Global Crops Innovations Organic

Institute on Science for Global Policy (ISGP)

Agricultural Development Local

Effective Farmers Genetic Public

Varieties Important Practices Traits

Sustainable Agriculture:
The Role of Plant Breeding Innovation

A program and conference organized, facilitated, moderated, and convened by the ISGP with support from the American Seed Trade Association and Euroseeds

(Internet Format)

November 17—18, 2020

Plant Diverse Production Market PBI

Implementation Sustainable Approaches

GMO Improved Seed Critical Risks

Scientific Consumers Plant Breeding

Participants Environmental Techologies

Food Information Systems Regulatory

Policy Climate Change Challenges Research

Benefits Gene Opportunities Current

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An ongoing series of dialogues and critical debates examining the role of science and technology in advancing effective domestic and international policy decisions

Institute on Science for Global Policy (ISGP)

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Introduction

Dr. George H. Atkinson
Founder and Executive Director, Institute on Science for Global Policy (ISGP)
and
Professor Emeritus, Department of Chemistry and Biochemistry and
College of Optical Sciences, University of Arizona
and
former Science and Technology Adviser to U.S. Secretaries of State
Colin Powell and Condoleezza Rice

Current Realities

Over the next few decades, the sustainability of global food and agricultural systems will be increasingly challenged by a diversity of converging factors, including the need to nourish a growing global population in the context of limited resources. Existing, emerging, and on-the-horizon agricultural tools for improved resource management (i.e., of soil, water, weeds, pests, and disease) and harvest and post-harvest practices present opportunities to address the critical need to achieve agricultural sustainability. Generations of evidenced-based research and discovery have driven dramatic scientific and technological advances in crop development by employing a range of tools and practices including breeding strategies, genotyping, phenotyping, and improved generational turnaround. While it is widely recognized that such tools can significantly impact the sustainability of food and agricultural systems worldwide, an understanding of the relationship between specific advances and agricultural sustainability remains open to interpretation, especially with respect to the diverse perspectives and priorities found throughout private sector, governmental, and public advocacy communities. Effective solutions to the challenges associated with sustainable agriculture consider real-world practicality, cultural sensitivities, differing nutritional needs, and public communication strategies that ensure credible science and technology is successfully integrated into publicly accepted, and strongly supported, policy decisions and real-world actions.

ISGP programs and conferences are designed to provide an egalitarian environment in which governmental, private sector, and public advocacy leadership can candidly engage in intense, respectful, and productive exchanges of the viewpoints and perspectives that often reflect divergent, contradictory priorities.

Through moderated critical debates and focused caucuses, ISGP conferences aim to identify Areas of Consensus (AOC) and Actionable Next Steps (ANS) supporting practical decisions grounded in credible scientific understanding and productive technological options to address real-world challenges.

Sustainable Agriculture: The Role of Plant Breeding Innovation (SA-PBI)

The ISGP SA-PBI program examined the role of plant breeding innovation in advancing effective domestic and international policy decisions concerning sustainable agriculture. The content of this ISGP book is derived from material presented at a conference on "Sustainable Agriculture: The Role of Plant Breeding Innovation (SA-PBI)" organized, facilitated, convened, and moderated by the ISGP. The ISGP SA-PBI program and conference were supported by the American Seed Trade Association and Euroseeds and was convened using an internet format on November 17 and 18, 2020. Though originally planned to convene in Brussels, Belgium as an in-person event in June 2020, the conference was restructured to convene virtually (on Zoom) due to travel and health restrictions associated with COVID-19. The conference engaged major scientific, technological, private sector, governmental, and public advocacy communities involved in food and agricultural systems. As primarily a European-United States dialogue, the scope of the conference included broad perspectives and priorities especially relevant to European and American communities. The agenda of the ISGP SA-PBI conference focused on how plant breeding innovations may support agricultural sustainability objectives and identified specific, ANS for achieving sustainability goals. While plant breeding innovations are often viewed as essential to increasing global supplies of nutritious, sustainable, culturally relevant, and economically viable food, pathways promoting plant breeding innovations need to optimize their effective uses and to appropriately identify any potential negative impacts or perceptions. Food and agricultural sustainability directly affect human health, environmental sustainability, economic prosperity, and societal stability worldwide.

The ISGP SA-PBI conference assembled a distinguished group of subject-matter experts and major stakeholders from the United States and Europe to debate major issues through the candid exchange of views and priorities using an ISGP debate/caucus format focused on identifying the AOC and ANS needed to accurately inform real-world, societal decision-making. ISGP SA-PBI conference participants, representing governmental, private sector, public advocacy, scientific, technological, and economic communities, viewed innovative plant breeding as a major component of sustainable agriculture while recognizing the diverse cultural, ethical, and economic challenges defining different 21st century societies.

ISGP invitation-only conferences, conducted under the Chatham House Rule (not-for-attribution), provide environments in which diverse, and often contradictory, views and priorities held by distinguished subject-matter experts and stakeholders can be debated. The invited participants in the ISGP SA-PBI conference represented individuals who often have responsibilities for making and/or significantly influencing major governmental, private sector, and community-led, decisions.

ISGP SA-PBI Conference Format

The organization of the ISGP SA-PBI conference began with extensive contacts and interviews by ISGP staff (exceeding 400) to identify highly credentialed and internationally recognized subject-matter experts and stakeholders. Four prominent subject-matter experts were invited to each prepare a concise (three-page) position paper articulating their views on the role of plant breeding innovation in meeting agricultural sustainability objectives. These position papers were structured around the understanding of each author concerning the current realities, related scientifically credible opportunities and challenges, and actionable next steps meriting broad support. One subject-matter expert was also invited to prepare an introductory paper outlining the scientific background of plant breeding and associated technological innovations.

The ISGP debate/caucus format, pioneered by the ISGP and modified for use on the Internet for the SA-PBI conference, included four, one-hour debates of each position paper (opened by a five-minute statement from the author followed by fifty-five minutes of debate). The four position paper debates (two debates on each day) were moderated by ISGP staff. The author of the introductory paper made a five-minute statement and answered clarifying questions to open the agenda on day one.

On both days, the debates were followed by a two-hour plenary caucus, which included all participants. The plenary caucus focused on identifying AOC and ANS. All debates and plenary caucus sessions were moderated by ISGP staff.

Through these modifications, the ISGP sought to capture as much of the spontaneity, intensity, and effectiveness of its widely endorsed in-person debate/caucus conference format while recognizing the limitations imposed by the COVID-19 pandemic and the resulting internet format used for the SA-PBI conference.

The entire ISGP SA-PBI conference required commitments from all participants and observers to obey the not-for-attribution restrictions embodied in the Chatham House Rule. About 32 invited participants actively engaged in questioning and about 33 invited observers, restricted to listening without any questioning, attended each day.

The ISGP staff used recordings of all debates, discussions, and the plenary caucuses to prepare not-for-attribution summaries. These recordings were held in the custody of the ISGP before being destroyed. The position papers and the not-for-attribution summaries are included in this book. The AOC and ANS emerging from the plenary caucus are also presented as Plenary Caucus Outcomes in the ISGP SA-PBI book.

In recognition that many of the terms commonly used in discussions of planting breeding are defined somewhat differently throughout global communities, an informal glossary of relevant terms was created and presented in the Appendix. This informal glossary was not intended to redefine any term, but rather to provide clarity with respect to the material presented here.

Concluding Remarks

The ISGP SA-PBI conference was designed to provide an environment that facilitates candid, critical debates and discussions leading to the identification of practical, real-world AOC and ANS relevant to the effective and responsible use of innovative plant breeding to improve agricultural sustainability. In recognition of the significant challenges to achieve sustainable agriculture in the 21st century now emerging from global climate changes, implementing effective, real-world approaches to sustainably feeding an increasing global population is critical worldwide. The role of plant breeding is central to many of these efforts. The ISGP continues to be committed to facilitating the identification of such productive outcomes while remaining neutral. All aspects of the ISGP SA-PBI conference conformed to the ISGP commitment to express no independent opinions nor lobby on any issue except rational thinking.

Plenary Caucus Outcomes

Preface

A two-hour Plenary Caucus was held on each day following two distinct position paper presentations and debates. The Plenary Caucuses engaged all participants in identifying Areas of Consensus (AOC) and developing Actionable Next Steps (ANS).

AOC defined overarching, aspirational goals that reflected the central themes identified in the introductory and position papers, presentations, discussions, and debates. Nine distinct AOC identified during the plenary caucuses are presented below.

ANS articulated specific tools, policy instruments, and actions that were considered to be effective pathways toward achieving specific AOC. A total of 56 ANS were identified and associated with specific AOC.

Themes

There was broad consensus on the need to achieve all United Nations (UN) Sustainable Development Goals (SDG). Special attention was given to the impact of plant breeding innovations (PBI) on Climate Action (Goal No.13), Zero Hunger (Goal No. 2), Responsible Production and Consumption (Goal No. 12), Decent Work and Economic Growth (Goal No. 8) and Life on Land (Goal No. 15). Within each targeted SDG, several recurring and overarching themes concerning the role of PBI in sustainable agriculture were identified. These themes represent general ideas and viewpoints that are collectively found, to varying degrees, among all AOC:

- Pursuing the SDG in agriculture, enabled by new and existing PBI focused on (i) enhancing disease resistance, (ii) reducing input requirements, (iii) improving orphan and underutilized varieties, (iv) augmenting food safety, (v) supporting farmer livelihoods, and (vi) achieving gender equality;
- Enhancing local adaptation and diversity in farming systems;
- Diversifying multiple aspects of farming systems (e.g., on-farm crop cultivation, markets, global crop diversity);
- Expanding options to use multiple tools (e.g., PBI) and approaches (e.g., participatory breeding, improved management practices) to achieve sustainable agriculture outcomes;
- Evaluating the impact of PBI based on how specific varieties are implemented

in practice (e.g., how does the innovation plus the system in which it is implemented contribute to sustainability);

- Expanding public engagement and dialogue in a science-based manner, conveying nuance in agricultural systems, and clearly distinguishing between safety, environmental, and social evaluations of innovations;
- Increasing collaborative action among stakeholders (e.g., through multi-stakeholder dialogues, research, and pilot projects)
- Taking a systems approach to crop development, markets, nutrition, sustainability, and trade;

While these themes were useful in structuring the conversation, additional themes emerged during the plenary caucus itself. The plenary caucus discussion underpinning AOC and their respective ANS is characterized by an annotation inserted after the AOC/ANS sections to reflect issues of significance to participants that were not necessarily captured in detail within the plenary outcomes.

Areas of Consensus (AOC) and Actionable Next Steps (ANS)

AOC1:

To create sustainable production systems that adequately feed people and effectively protect the environment, a systematic approach to providing nutritious food and animal feed year-round with a vibrant value chain (e.g., economically viable, coexisting market product channels) is needed. A focus on enhancing local adaptation and diversity is critical to achieving these goals.

- **ANS1.1:** Use PBI as a tool to support the production of nutritious food at prices that ensure affordability for consumers and sustainable livelihoods for farmers, while protecting the environment in the context of climatic changes.
- **ANS1.2:** Increase the diversity of (i) varieties, (ii) crop species, and (iii) production systems in agriculture.
- **ANS1.3:** Collect data on, and be informed by, farmer knowledge regarding the impact of climate change on crops, farmer needs, and experiential innovation to guide plant breeding efforts in real time.
- **ANS1.4:** Engage society in dialogues exploring both the real-world, potential advantages, limitations, and capabilities of plant breeding technologies to ensure that the improvement of crop varieties available to farmers, the food industry, and consumers is agile in responding to societal expectations.
- **ANS1.5:** Implement plant breeding programs that contribute to a vibrant value chain. Develop a portfolio of locally adapted, low-input varieties that provide adequate regional nutrition year round.

AOC1 Plenary Caucus Annotation

Participants discussed the need to clarify the definition of effective pricing. In particular, ensuring affordable prices for consumers, without undercutting sustainable livelihoods for farmers, was cited as critical, especially as it related to the minimization of negative environmental externalities (e.g., eutrophication due to nutrient runoff) associated with agriculture. It was also suggested that achieving sustainable livelihoods for consumers (in addition to farmers) would be a more effective approach to ensuring that an appropriate valuation of farming is captured in realistic food prices, as opposed to prioritizing low-cost food. While regional adaptation and diversity within agricultural systems were uniformly viewed as critical aspects of sustainable agricultural systems, it was noted that international trade is not inherently unsustainable.

AOC2:

To meet diverse and changing consumer values and environmental goals, multiple forms of agriculture need to coexist effectively. No single approach can achieve the desired outcomes for the wide range of societal and environmental issues relevant to diverse global agricultural environments. It is critical to increase diversity (e.g., production methods, consumer products, marketplace structures) in food and agricultural systems and to ensure that all technology is available and affordable to all food system stakeholders.

- **ANS2.1:** Recognize that different plant breeding methods (e.g., participatory, organic) and technologies (e.g., gene editing) will vary in efficacy depending on the agricultural context (e.g., cultural, economic, scientific, environmental) in which they are implemented.
- **ANS2.2:** Collect comparative data across diverse crop cultivation and agricultural management systems to enable informed consumers to access food choices appropriate to their health and environmental priorities.
- **ANS2.3:** Open a dialogue among the private sector, public advocacy, governmental, and scientific communities to clarify effective coexistence pathways (i.e., the coincident cultivation of conventional, organic, intellectual property, and genetically engineered crops).
- **ANS2.4:** Implement integrated cropping systems in which varieties derived from new PBI are cultivated within agroecological management systems to achieve SDG.
- **ANS2.5:** Integrate organic farming with agroecology to achieve SDG.
- **ANS2.6:** Invest in general plant breeding efforts that lack effective market incentives but have the potential to significantly contribute to achieving SDG. In the absence of private sector interest, invest public funding in the development of underutilized crops and varieties that support positive environmental impact and ecosystem services (e.g., nutrient cycling, soil formation, carbon sequestration, water regulation, erosion regulation).
- **ANS2.7:** Conduct true-cost accounting (i.e., accounting that considers externalized costs not embedded in the price of food), specifically focused on the positive and negative environmental impacts of food production and consumption.

AOC2 Plenary Caucus Annotation

The importance of integrating the perspectives and priorities of consumers, breeders, farmers, processors, and retailers into breeding programs was strongly emphasized. Activities engaging the aforementioned stakeholders were suggested to support the development of breeding programs that deliver crops that (i) support sustainability goals, (ii) can be effectively utilized and incorporated throughout the value chain, and (iii) receive broad endorsement by consumers.

AOC3:

The current absence of global consensus on how sustainable consumption and food production systems can effectively use PBI to respond to crises emerging from climatic changes, decreased biodiversity, and expanding human dietary and health needs significantly complicates regulatory approaches and inhibits progress towards achieving SDG. To overcome this challenge, a common vision, especially among European and United States communities, concerning the structure of a sustainable food and agricultural system is essential to providing a foundation for real-world policy decisions and practical actions. Any commonality of purpose centered on addressing the often diverging political realities, needs to be identified within the framework of credible scientific information, especially regarding the role of PBI in achieving SDG.

- **ANS3.1:** Engage environmental and non-governmental organizations representing value-based production systems (e.g., organic farming) to identify their views on the necessary parameters regarding the acceptable use of PBI technology, especially as they relate to human health and environmental safety concerns. Emphasis needs to be placed on finding circumstances to identify mutually supported options toward the coexistence of multiple systems of production.
- **ANS3.2:** Recommend the revision of the European Union (E.U.) legislation regarding new plant breeding techniques with consideration of the impact of the current designation of gene editing as genetic modification on the pursuance of the goals of the "Farm to Fork" strategy (e.g., the future ability to grow gene-edited, pest resistant varieties may contribute to the faster achievement of pesticide reduction goals).
- **ANS3.3:** Support the improvement of technology adoption within food and agricultural supply chains by engaging consumers, farmers, and other value chain actors in identifying desired crop attributes (e.g., price, nutrition).
- **ANS3.4:** Engage publicly trusted and credible scientific voices to

communicate with governments and the public *writ large* on the scientific and technological tools and approaches used to achieve various goals throughout food and agricultural supply chains.

- **ANS3.5:** Ensure that the *ISGP Sustainable Agriculture: The Role of Plant Breeding Innovation* (SA-PBI) dialogue is part of the UN food system summit process. Include the ANS identified in the ISGP SA-PBI conference as well as its multi-stakeholder approach is part of the 2020-2021 United Nation Food Systems Summit "Game Changers".

AOC4:
To enable technology applications for sustainable outcomes, it is critical to (i) earn broad societal license (i.e., legitimacy, credibility, trust) for PBI and (ii) ensure consumer demand for technology use throughout agricultural supply chains.

- **ANS4.1:** Develop and enhance transparency activities around products and production processes through various approaches and methods.
- **ANS4.2:** Implement case-by-case, risk-benefit assessments of PBI that distinguishes between consumer perceptions versus credible evaluation by scientists and technologists.
- **ANS4.3:** Issue a joint statement (from ISGP SA-PBI participants) regarding the safety aspects of PBI, their applications, and their products. Such communications need to focus on the safety of products (rather than the process of developing the product) and how they support sustainability with respect to climatic changes. Collectively, communications need to improve technology acceptance among consumers.
- **ANS4.4:** Conduct public and private research on consumer attitudes and perceptions concerning new technologies, including on the impact of food labeling on consumer understanding. Encourage the European Commission (EC) to explore the development of a product labeling framework that includes nutritional, environmental, societal data for all of the diverse farming techniques as an action item within the EC Consumer Agenda.
- **ANS4.5:** Conduct narratology and conflict analysis and resolution research to clarify how views, values, and identities impact public understanding of new PBI (e.g., gene editing). Develop and implement tailored communication plans targeting different stakeholders along the food chain.
- **ANS4.6:** Provide information to the public on the nuanced realities of food production and efficiency in diverse agricultural systems. Avoid using an

information deficit model and refrain from over exaggerating the benefits or risks of any particular technology in communications with consumers.

- **ANS4.7:** Engage consumers in discussions regarding what to produce in order to increase consumer buy-in earlier in the product development process. Develop systems that allow breeders to use consumer input to identify the goals of their breeding programs for new varieties.
- **ANS4.8:** Prioritize the development of crop varieties that (i) taste better, (ii) support public health and food safety (e.g., by eliminating or reducing allergens, toxins, and hospitality to human pathogens), and (iii) facilitate sustainability (e.g., by reducing food waste).
- **ANS4.9:** Promote collaboration throughout the supply chain (e.g., among farmers, food industry, and retailers) to support innovation projects focused on developing products using new PBI. Create excitement around products using new varieties via targeted marketing.
- **ANS4.10:** Engage food processors, retailers, and the food service industry to communicate the safety of new technologies, including PBI (e.g., gene editing), to consumers.
- **ANS4.11:** Create a demand market that drives economic viability for farmers.
- **ANS4.12:** Involve stakeholders in all aspects of agroecological production systems.

AOC4 Plenary Caucus Annotation

The need to more effectively support public understanding *writ large* of the different tools and methodologies used to make food products was repeatedly cited together with the need to improve the clarity and accuracy of information used by consumers to make informed decisions regarding their food choices. It was suggested that there are opportunities to use labeling to articulate how various tools and methodologies were used to achieve specific health or sustainability goals in *all* food products (i.e., rather than just those employing genetic engineering) as well as how they relate to sustainability challenges.

AOC5:

For UN member states to achieve the SDG, smallholder farmers need to be empowered in their efforts to address food and nutrition security as well as climate and energy resource challenges. PBI policy development needs to (i) highlight the global nature of farming and markets and (ii) incorporate

farmer perspectives, and (iii) ensure that farmers worldwide have access to the same necessary tools to meet SDG.

- **ANS5.1:** Improve and expand the utilization of co-creation strategies in development of public and private sector plant breeding research agendas to more effectively target the needs of smallholder farmers.
- **ANS5.2:** Create environments that enable diverse and competitive seed markets (i.e., without market power concentration) to ensure that seeds are accessible to all farmers, including marginalized smallholders. Ensure the economic sustainability of the plant breeding enterprise (e.g., public, private, community based).
- **ANS5.3:** Initiate collaborative, pre-competitive discussions within the seed industry (e.g., via a consortium or a platform of several players) to support the development of underutilized varieties. Share pre-competitive research results within the seed sector to support the discovery process and thereby improve the commercialization of a wider range of crops and varieties.
- **ANS5.4:** Develop and implement new business models within the seed sector to address the financial constraints faced by smallholder farmers in purchasing quality seed and crop insurance (e.g., by linking crop insurance to seeds while incentivizing good agricultural practices). Increase shared benefits among trait developers and farmers.
- **ANS5.5:** Expand policy, research, and public-private partnerships focused on opportunities to use neglected and underutilized crop species, especially in long-lived perennials and crops with a limited geography for cultivation (e.g., crops grown using cuttings).
- **ANS5.6:** Promote policy and public investment in research on smallholder access to a wide range of agricultural technologies and management practices (e.g., agroecology).
- **ANS5.7:** Develop more effective distribution channels for new and current innovations to support farmer livelihoods and sustainability. Enhance the accessibility of knowledge for farmers by utilizing new and existing production and distribution channels of materials to farmers.
- **ANS5.8:** Emphasize that the critical role of youth and women in agriculture is strongly supported and publicly highlighted by ensuring all groups have equal access to the same tools, financial resources, and professional opportunities.
- **ANS5.9:** Improve and implement transdisciplinary methods to address climate change and agricultural sustainability and to understand agronomic, cultural, and genetic barriers to adoption of new crops and varieties.

Utilize small-scale pilot projects as learning exercises to evaluate tangible experiences and explore how to improve the current interface between societal priorities, especially with respect to addressing societal complexities associated with food and agricultural issues.

- **ANS5.10:** Urge governments to engage in South-South and Triangular cooperation to ensure smallholders have access to a range of options.

AOC6:
To support the development of zero-carbon (e.g., carbon neutral/positive) agricultural systems without unacceptable yield penalties, it is necessary to employ all existing and new plant breeding tools to quickly incorporate climate smart traits into new and existing crops.

- **ANS6.1:** Recognize that conventional breeding systems (e.g., hybridization, polyploidy, induced mutation) are, in themselves, a robust solution that can potentially be enhanced by new technologies. New PBI can be one important component of making food and agricultural production more sustainable. Ensure that breeding programs using conventional methods continue to receive funding along with breeding programs employing new technologies and approaches.
- **ANS6.2:** Increase the accessibility of the full range of plant breeding tools for all users, while ensuring that the most efficient, context-specific (e.g., scientific, economic, cultural) form of breeding is employed. Utilize the full toolbox of plant breeding to focus on developing resistant, resource-efficient, climate adapted, high yielding varieties in light of current and anticipated challenges associated with climate adaptation and mitigation and evolving population dynamics.

AOC6 Plenary Caucus Annotation

While it was broadly agreed that innovation in plant breeding is needed to address the major environmental, societal, and economic challenges of the 21st century, it was noted that there was less consensus on the specific technologies and approaches that need to be implemented in each case. There was general agreement that no single technology will be suited to all contexts; therefore, a multitude of approaches and methods will be needed to provide farmers with a wide selection of varieties to meet their specific context (e.g., geographic, economic, cultural).

Gene editing technology was used to exemplify how breeding methods can be appropriately matched to contextual elements. Specifically, it was suggested that gene editing is an appropriate tool for achieving simple traits, whereas genomic selection and environmental modeling may be more effective for achieving complex traits. Improvements in decentralized breeding, participatory breeding, and statistics were noted as potentially more effective approaches when breeding for heterogeneous environmental conditions compared to gene editing approaches. This suggestion was challenged, and it was strongly asserted that technologies need to be considered within the context of future applications, in addition to current capacities.

Significant attention was given to examining the relative importance of different breeding approaches. While all participants agreed that conventional breeding systems are, and will continue to be, critically important to the success of agricultural systems, there were divergent opinions concerning whether conventional breeding is a "robust" solution (ANS6.1). In particular, there was concern surrounding the idea that conventional breeding is sufficient, in and of itself, to respond to the multiple converging factors impacting agricultural communities worldwide (e.g., climate change, shifting population dynamics, consumption patterns). Conversely, it was strongly asserted that PBI (e.g., gene editing) will not solve all agricultural challenges. Ultimately, the need for a multitude of breeding approaches, based on context, was reaffirmed among most participants. Within this general agreement, ensuring that the innovation ecosystem (e.g., regulation, funding) enables breeders to use the tools they deem most useful to achieve the desired crop varieties was emphasized.

AOC7:
Shifting attention to evaluation of products, rather than processes, while noting concerns expressed by the organic community, was considered critical to improving the efficiency and speed with which new products are introduced and the long-term sustainability of the food and agricultural systems, especially with respect to achieving SDG.

- **ANS7.1:** Assess the impact of plant breeding used in farming systems in terms of how products containing specific varieties, together with sustainable management practices, support SDG, rather than the specific breeding method used. Include the acceptability of the environmental impact (i.e., trade-offs) on a case-by-case basis in evaluations of PBI technologies (e.g., herbicide tolerance enables low-till agriculture, but contributes to resistant weeds).
- **ANS7.2:** Distinguish between sustainability, production, and the plant breeding method used to create varieties for sustainable agriculture.
- **ANS7.3:** Ensure the economic sustainability of production farms as a criterion for the assessment of agricultural sustainability.
- **ANS7.4:** Focus on an interconnected supply chain and recognize the

consequences of decisions made by individual actors within the food value chain on all other stakeholders.

AOC7 Plenary Caucus Annotation

It was generally recognized that PBI can be used to create varieties that facilitate efficient, sustainable production methods. Significant discussion centered on how products (i.e., crop varieties and their associated traits) versus processes (i.e., breeding methods) need to be incorporated into sustainability assessments. It was noted that a breeding method is not, in and of itself, sustainable or unsustainable. Rather, it was recognized that the sustainability of breeding efforts can be evaluated based on how they contribute to a sustainable management system (e.g., by enabling reductions in pesticide use, or the use of mixed cropping systems). Specifically, many participants expressed that the most appropriate technologies and methods used in breeding programs will depend largely on specific contexts (i.e., on a case-by-case basis). A more appropriate assessment of sustainability would focus on the context of a certain variety, production system, and location.

Given the highly interconnected nature of food value chains, from plant breeding to consumption, it was noted that the decisions of individual actors have impacts throughout the food supply chain. As a consequence, it was repeatedly emphasized that stakeholders need to work together to ensure that decisions made within plant breeding programs consider the entire system (e.g., how consumers will respond) to ensure the effective use of resources for innovation. Moreover, collective identification among stakeholders of scientific goals (e.g., drought tolerance, lower input, increased yield) within breeding programs need to also focus on anticipating the needs of farmers and markets.

AOC8:

To optimize the positive impacts of food and agricultural systems on environmental sustainability and on human health, transformations within not only agricultural production, but within human diets and food consumption are needed (e.g., it is often suggested that reducing meat consumption especially in the United States, Europe, and China).

- **ANS8.1:** Assess environmental sustainability along the entire value chain from plant breeding to production to consumption.

AOC8 Plenary Caucus Annotation

There was general consensus on the need to shift diet patterns in order to achieve SDG outcomes in food and agriculture (e.g., less meat consumption). It was strongly asserted and agreed among participants that efforts to reduce meat consumption need to focus especially on the United States, Europe, and China. The need for developed nations to avoid dictating appropriate diets in more resource-constrained regions of the world and to allow “appropriate” diets to be defined on a regional case-by-case basis, with consideration for socioeconomic and cultural elements was strongly expressed. It was noted that increasing meat consumption in some places may be important for meeting urgent nutritional challenges.

AOC9:

It is critical to hold ongoing, open discussions and debates based on scientific evidence to evaluate the nuanced societal, ecological, and economic benefits and risks of various PBI. Special attention needs to be given to the interdependencies of farming systems.

- **ANS9.1:** Develop a transparent framework for evaluating PBI that includes economic, societal, human health, and nutritional impacts.
- **ANS9.2:** Initiate studies and communication approaches that better describe the ecological and economic risks associated with delaying the application and implementation of PBI.
- **ANS9.3:** Balance the urgent nutritional needs of the growing population against the curiosity for continual reassessment of technologies with minimal scientifically demonstrated environmental risk.
- **ANS9.4:** Move away from the debate on technologies and focus on articulating options to address urgent challenges. Communicate the demonstrated and potential positive impacts on social, economic, and livelihood indicators (e.g., natural, financial, social, physical, and/or human capital) of innovations in crop characteristics through applications of new PBI (e.g., impact of specific biofortified crops on reducing anemia, mortality, blindness, and cognitive delay).
- **ANS9.5:** Emphasize the amount of multigenerational, multilocation testing conducted on farmers’ fields to assess varieties developed by various PBI methods.
- **ANS9.6:** In communications, be more realistic about the benefits or risks of any particular technology.
- **ANS9.7:** Promote public dialogues focused on the benefits, challenges, risks, and opportunities of specific breeding methods and production systems. Place more value on social, economic, and ecological sciences. Clearly distinguish social and economic evaluations from environmental and human safety evaluations.

- **ANS9.8:** Include ethical and values-based topics in science-based dialogues focused on technology in agricultural systems to manage uncertainty when balancing values and other factors during the risk-management phase.
- **ANS9.9:** Engage in a discussion on the potential benefits and risks related to the use of gene editing among plant breeding among breeders, scientists, and stakeholders. Determine a proper timeline of transition from safety certification to public communication regarding safety based on credible evidence.
- **ANS9.9:** Engage in the dialogue towards clear policy options for genome editing in the E.U. and ensure broad stakeholder engagement in the month ahead (December 2020) as the EC releases its study on the current directive.

AOC9 Plenary Caucus Annotation

The difference between risk assessment and risk management was clarified during the discussion of AOC9.7. Specifically, it was noted that assessment focuses on evaluating environmental and human safety risks, whereas management focuses on how to address risk (e.g., through policies or practices). Risk management may include consideration for how values are incorporated into the discussions on, and ultimate implementation of, PBI technologies. The importance of fostering a more science-based dialogue on PBI was emphasized on multiple occasions. It was noted that policy development discussions often focus on political nuances that can overlook (i) the role of science-based evidence underlying a given issue, and (ii) how science and technology advances might contribute to specific policy goals (e.g., SDG). This was noted as a critical issue for the intersection of science and policy.

The Role of Plant Breeding Innovation (SA-PBI) Conference Agenda

organized, facilitated, convened, and moderated by
The Institute on Science for Global Policy (ISGP)
with support from
American Seed Trade Association and Euroseeds
convened on a two-day Virtual (Internet) Format
November 17 — 18, 2020

DAY ONE: Tuesday, November 17, 2020

14:00 - 14:30 CET[1]
(08:00 - 08:30 EST)[2]

Technical Start and Instructions *(participants check in via Zoom)*

Program Overview
Kat Wheeler, Program Director and Senior Fellow, ISGP
Dr. George Atkinson, Founder and Executive Director, ISGP

Technical Instructions
Ciaran Fitzpatrick, Senior Fellow, ISGP

14:30 - 15:00 CET
(08:30 - 09:00 EST)

Introductory Presentation and Question and Answer Session
Moderator: Daniela Baeza, Senior Fellow, ISGP
"*Then and Now: A Scientific View on Plant Breeding and Technological Innovation*"
Author: **Dr. Rene Smulders**, Ph.D., Business Unit Manager, Plant Breeding, Wageningen University & Research, The Netherlands

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[1] Central European Time Zone
[2] United States Eastern Time

15:00 - 16:00 CET (09:00 - 10:00 EST)	**Debate One (Position Paper One)** Moderator: Kat Wheeler, Program Director and Senior Fellow, ISGP *"Roles of Plant Breeding for Sustainable Agriculture and Food Systems"* Author: **Dr. Matin Qaim**, Ph.D., Professor, University of Göttingen, Germany
16:00 - 17:00 CET (10:00 - 11:00 EST)	**Debate Two (Position Paper Two)** Moderator: Margaret Patkus, Senior Fellow, ISGP *"Systems-based Concepts for Innovative Organic Plant Breeding"* Author: **Dr. Monika Messmer,** Ph.D., Senior Scientist for Organic Plant Breeding, Baselland, Switzerland
17:00 - 17:10 CET (11:00 - 11:10 EST)	**Break**
17:10 - 17:15 CET (11:10 - 11:15 EST)	**Review of Plenary Caucus Format** Margaret Patkus, Senior Fellow, ISGP
17:15 - 19:15 CET (11:15 - 13:15 EST)	**Moderated Plenary Caucus** Moderator: Kat Wheeler, Program Director and Senior Fellow, ISGP Scribe: Roxanne Hoorn, Adjunct Fellow, ISGP Scribe: Arleigh Truesdale, Fellow, ISGP
19:15 (13:15 EST)	**Adjournment** Speaker: Dr. George Atkinson, Founder and Executive Director, ISGP
19:15 - 20:15 CET (13:15 - 14:15 EST)	**OPTIONAL: Informal Continuing Discussion** Moderators: Dr. George Atkinson, Founder and Executive Director, ISGP Kat Wheeler, Program Director and Senior Fellow, ISGP

DAY TWO: Wednesday, November 18

14:00 - 14:15 CET (08:00 - 08:15 EST)	**Technical Start**
	Day 2 Program Overview Kat Wheeler, Program Director and Senior Fellow, ISGP **Review of Technical Instructions** Ciaran Fitzpatrick, Senior Fellow, ISGP
14:15 - 15:15 CET (08:15 - 09:15 EST)	**Debate Three (Position Paper Three)** Moderator: Daniela Baeza, Senior Fellow, ISGP "*Plant Breeding Innovation for Sustainability*" **Dr. Carl M. Jones,** Ph.D., Plant Sciences Director, MARS Advanced Research Institute, Davis, California, U.S.
15:15 - 16:15 CET (9:15 - 10:15 EST)	**Debate Four (Position Paper Four)** Moderator: Ciaran Fitzpatrick, Senior Fellow, ISGP *"A New Generation of Plant Breeding for a Next Generation of Farmers"* **Jannes Maes,** President, The European Council of Young Farmers (CEJA), Flanders, Belgium
16:15 - 16:30 CET (10:15 - 10:30 EST)	**Break**
16:30 - 18:30 CET (10:30 - 12:30 EST)	**Moderated Plenary Caucus** Moderator: Kat Wheeler, Program Director and Senior Fellow, ISGP Scribe: Roxanne Hoorn, Adjunct Fellow, ISGP Scribe: Arleigh Truesdale, Fellow, ISGP
18:30 - 19:00 CET (12:30 - 13:00 EST)	**Final Remarks, Review, & Adjournment** Dr. George Atkinson, Founder and Executive Director, ISGP

Introductory Paper
Then and Now: A Scientific View on Plant Breeding and Technological Innovation**

M.J.M. (René) Smulders, Ph.D.
Business Unit manager, Plant Breeding, Wageningen University & Research, Wageningen, The Netherlands

Origins of Agriculture and Plant Breeding

Humans initiated agriculture independently in various regions across the world from 9,500 B.C. onward. Wheat, barley, peas, and lentils were cultivated in the Middle East, beans and potatoes in South America, rice in China and other locations in Southeast Asia, bananas in New Guinea, maize in Central America, and sorghum in Africa, to name a few. Starting with genetically diverse populations, the process of sowing, cultivating, harvesting, and using various crop species in agriculture, led to the intentional and unintentional selection of plant types with increasingly desirable traits (e.g., more compact plants with larger seeds or fruits). Mutations that led to the omission of undesirable traits (e.g., seed shattering, production of protective compounds that are toxic to humans) were also selected. This process, called domestication, has changed the appearance as well as the genetic composition of agricultural crops today, to such an extent that they are now hardly recognizable compared to the wild ancestors of our crops.

For most of agricultural history, neither the genetic basis of traits nor their inheritance was understood. By 1700, rose breeders realized that they could influence the traits of offspring by selecting specific parents for reproduction. These breeders used this insight to produce the first hybrids between European and Chinese roses. It was not until 1900, however, that Mendel's laws on genetic inheritance laid the foundation for plant breeding as a science.

Plant breeding is defined as the art and science of changing the genetics of plants for the benefit of mankind. The objectives of plant breeding are to develop crop varieties with improved yield and performance stability, and resistance to abiotic (e.g., climate) and biotic (i.e., diseases, insect pests) stresses. Simultaneously, breeders seek to improve diverse value-added traits such as (i) nutritional quality (e.g., protein and starch content in peas, beans, and cassava), (ii) industrial properties (e.g., baking quality in wheat, frying quality in potatoes), (iii) size, shape, and color (in flowers and vegetables), and (iv) taste and shelf life (in fruits).

Technological Development in Plant Breeding in the 20th Century

Combining multiple traits is a slow and tedious process that involves eliminating all offspring with one or more undesired traits. For example, a new apple variety with a superior combination of traits is selected from approximately 15,000-20,000 unique seedlings, and this requires a minimum of 20 years. Breeding for specific traits may take much longer. For a scab resistance gene from a wild apple species, the breeding process lasted 50 years and required four backcrosses to develop scab-resistant apples with sufficient size and taste. For that reason, plant breeders continuously seek new tools to remove barriers, accelerate steps, and improve precision and efficiency in breeding programs.

In the 20th century, the human population expanded from 1.6 billion to over 6 billion. Food production has increased to accommodate this pace of growth. This increase was partly enabled by improved crop varieties. Major junctures in the development of the "toolbox" of available plant breeding technologies within the 20th century include:

- 1920: F1 (Filial one) hybrid breeding first applied in maize, an important component of the six-fold increase in yield per hectare during this century.
- 1930s: Mutation breeding is first used on large populations of plants to increase genetic variation in desired traits (e.g., seed-lessness in fruits, color in flowers, disease resistance in cereals).
- 1950s: Tissue culture techniques developed for micropropagation and multiplication, and for the rescue of embryos in difficult crosses.
- 1960s: Dwarfing traits in wheat and rice lead to the 'Green Revolution' that boosted yield.
- 1980: Genetic modification (GM) of plants invented in Ghent (Belgium).
- 1990s: DNA markers used for Marker-Assisted Selection.

New Plant Breeding Techniques in the 21st Century

Agriculture now faces a new and critical challenge: producing food sustainably for a population that will grow to an estimated 9.5 billion by 2050, while simultaneously coping with changing conditions due to global warming. Society demands production on less land to conserve biodiversity and with fewer inputs of pesticides and fertilizers. Consumers and industry want products that meet their requirements and address their needs. Meeting these challenges will require, amongst other solutions, new varieties that can produce effectively under conditions of drought and heat, withstand pests and diseases, and fit optimally into more diverse production systems (e.g., organic, circular, biodiverse, agroecological or integrated) and in other physical settings (e.g., urban, vertical agriculture).

The availability of information essential in responding to these challenges has dramatically increased due to scientific and technological progress. Since 2000, DNA sequencing technology has advanced radically with a 100-fold reduction in costs. Since the first crop genome (rice) was sequenced in 2002, the complete genomes of 60 additional crops have been mapped. Breeders are now able to sequence the major parents in their breeding program(s) to better understand their genetic potential. Linking this genetic information to underlying traits is enabled through high-throughput phenotyping with drones and hyperspectral cameras in combination with apps enabling the input of observations directly into databases. Using tens of thousands of markers that tag genetic differences across chromosomes and between the parents, the inheritance of traits from parents to offspring can be tracked and, based on this information, the most promising offspring can be selected already in the seedling stage.

This tremendous increase in the availability of information makes breeding more efficient, but not automatically faster in terms of the breeding generations required. For that, a variety of additional tools, referred to as new plant breeding techniques (NPBT) or new genomic techniques (NGT) have been developed.

Tools involving genetic transformation (without the introduction of foreign genes):

- ***Cisgenesis and intragenesis*** introduce genes such as disease resistances from other varieties of the same species that are useful in outcrossing plants in which a variety is maintained by vegetative propagation (i.e., asexual) (e.g., in fruit trees and potatoes).
- ***RNA interference*** introduces an inverted piece of an unwanted gene that silences the expression of the unwanted gene (e.g., genes encoding allergens) or even a gene family.

Tools involving transitory genetic modification (only present in one stage of the breeding process)

- ***Early flowering*** introduces a flowering time gene to speed up breeding cycles in intermediate generations (e.g., in fruit tree breeding) while the gene is crossed out in the final generations. Early flowering produces plants that are identical to what can be bred without using the technique, but obtained often decades earlier.
- ***Gene editing with CRISPR/Cas*** induces targeted mutations in specific

genes and can be used to copy useful changes that exist in other varieties or in wild relatives directly into breeding lines.

Other beneficial tools, which do not fall under the category of NPBTs, include:

- ***Speed breeding*** shortens the generation time during the breeding process (e.g., of cereals) by adjusting the growing conditions.
- ***Genomic prediction*** is a technique to predict the performance of parents and offspring based on statistical associations with DNA markers in test crosses that enables the efficient selection of the most ideal parent and offspring lines.

Plant breeders employ crossing and selection, using a range of tools from their toolbox as deemed useful. No single tool can replace all others.

However, gene editing with CRISPR/Cas9, invented in 2012 in France and California, has revolutionized genetic and physiological research in plants and microorganisms as reflected in the 2020 Nobel Prize in Chemistry being awarded to its founders. Gene editing can be applied in various ways. In plant breeding, CRISPRCas9 may be used to induce targeted mutations (i.e., mostly small insertions or deletions, termed SDN-1) in or near genes. The resulting mutations may be identical to naturally occurring mutations that exist in related plants. The mutations are the same as those induced using random mutation breeding and require only a small number of plants without the need for thousands of random mutations. For plant breeders, it therefore is a tool that is faster and much more precise than random mutation breeding. Gene editing also enables breeders to modulate gene expression levels, rather than switching a gene off completely. In some cases, it may avoid tedious crosses and backcrosses, thereby conserving a decade or more of breeding efforts. Nonetheless, application of gene editing still requires knowledge of the functional gene for a trait, so it is most suitable for genetically simple traits (e.g., disease resistance), especially when those traits are encoded by gene families (e.g., allergens, gluten). Gene editing may be less suitable for genetically and physiologically complex traits such as yield. In addition to knowledge of the functional gene for a trait, DNA sequence information is also required, but that information is much easier to generate today, including for minor and orphan crops.

One concern with gene editing is the possible occurrence of off-target mutations (in similar targets elsewhere in the genome). In plant breeding, gene editing is always used in the context of extensive, multi-year selection of the progeny. This screening step gave random mutation breeding a history of safe use and will also do so for gene editing as the number of mutations is much smaller.

These inventions and types of applications were not foreseen when formulating regulations on genetically modified (GM) plants in which foreign genes were introduced, including the 2001 European Directive on genetic modification drafted just a few years following the cultivation of the first GM field crop in 1995. Notably, the European Commission has recently started an enquiry to stakeholders to assess whether the implementation of the Directive needs revision in view of the new genomic techniques.

Outlooks

What types of traits, varieties, crops, and forms of agriculture are needed to produce the range of food, raw material, and ornamental products by 2050? How can stakeholders more effectively engage in the meaningful exchange of ideas, initiate the necessary research programs, and optimize breeding programs in those directions while recognizing that the future is uncertain and that there is not a single solution?

** ***An introductory paper prepared for presentation at the conference on Sustainable Agriculture: The Role of Plant Breeding Innovation, organized, facilitated, convened, and moderated by the Institute on Science for Global Policy (ISGP) with support from the American Seed Trade Association and Euroseeds.***

Introductory Paper
Discussion Summary

This not-for-attribution summary of the discussion concerning an introductory paper authored by Dr. Smulders was prepared by the Institute on Science for Global Policy (ISGP) staff from an audio recording, and its transcription. The introductory paper was intended to provide a general scientific and historical background on plant breeding. The ensuing discussion was initiated by a five-minute statement from Dr. Smulders, followed by a discussion with all participants for the remainder of a 30-minute session. The summary of this discussion represents the best effort of the ISGP staff to accurately capture the questions posed by all participants, as well as responses offered by Dr. Smulders. Given the not-for-attribution format of the ISGP/SA-PBI conference, the views comprising this summary do not necessarily represent only the views of Dr. Smulders. Rather, it is, and needs to be read as, an overview of the exchange of views and priorities among participants.

Current Realities

The discussion of the introductory paper, which focused on the historical development of plant breeding, opened with questions concerning how plant breeding, or plant breeding innovations (PBI), can make significant contributions to achieving agricultural sustainability under the challenges presented by rapidly changing climate conditions, a growing global population, and finite arable land. It is the obvious conclusion that humankind historically has been breeding for traits to meet environmental conditions and nutritional needs with the help of available tools and constantly evolving technologies. These uses of plant breeding have been accelerated by the development of genetics as a field of science since approximately 1900. It was asserted that, during the 1900s, technological innovations increased the speed and precision in plant breeding, thereby improving the capacity of agriculture to provide food for a growing population. Alongside this technological evolution, a shift has occurred with regard to which stakeholders undertake breeding processes. During the 20th century, plant breeding was mainly performed by scientists and specialized seed companies, in contrast to the breeders of the past (i.e., farmers selecting and saving seed on their land). In the 21st century, the need to engage a wider range of stakeholders (e.g., producers, civil society organizations, consumers, policymakers) in the development of private sector breeding programs to increase their efficacy and respond to concern over centralization has been increasingly recognized.

To preserve biodiversity and reduce habitat destruction in the context of climatic changes, it was asserted that agriculture needs to provide more nutritious food for more people on less land. It was suggested that the use of existing agricultural land needs to be optimized in terms of sustainability and productivity through a reduction of fertilizer/pesticide application and the introduction of new varieties with traits adapted to local and regional conditions (e.g., drought resistance, deeper rooting). It was maintained that technologies will be effective in addressing these efforts only if all plant breeders have access to a "toolbox" with a broad range of appropriate technologies. The plant breeding community encompasses breeders within public institutes, large breeding companies, small and medium-sized enterprises (SMEs), and others working collectively on a wide range of innovative crop and ornamental breeding initiatives. It was contended that debates surrounding PBI (e.g., genetically modified organisms) are often too narrowly focused on specific technologies rather than how PBI can be implemented effectively in tandem with other methods (e.g., agroecology, agroforestry) to achieve more sustainable, locally-adapted agricultural systems worldwide.

It was noted that random mutation plant breeding is widely considered to have a history of safe use, and that such safety assessments are often used to support claims regarding the safety of gene editing *writ large*. The validity of this correlation between the two technologies was questioned. In this regard, it was noted that gene editing can introduce the same mutations that can be induced by random mutation breeding, but that gene editing does not cause other coincidental mutations. Furthermore, gene editing is considered more versatile and precise than inducing random mutations. Therefore, it was asserted that plant breeding using gene editing requires fewer crosses and selections to breed out undesirable results compared to random mutation breeding. It was also asserted that both technologies are safe because their use occurs within the context of plant breeding programs, which entail the removal of undesirable changes to the genome over several generations.

Scientifically Credible Approaches and Challenges

It was posited that shifting population dynamics and decreasing land availability emphasizes that all forms of agriculture systems, existing and emerging, be tailored to effectively address the myriad, interconnected challenges of the 21st century food systems. The sustainability of agricultural systems can be strengthened by selecting traits and varieties that are tailored to specific crops and ecological conditions, found locally and regionally. In some cases, important traits may include improved drought resilience, disease resistance, and deeper crop rooting. It was noted that the application of new traits and varieties requires the consideration of potential long-term effects on critical environmental indicators (e.g., biodiversity and soil health). A cautionary comment suggested that the use of agricultural practices, even those generally considered to be ecologically beneficial (e.g., agroforestry systems with shade planted coffee or cocoa) may negatively impact above-ground biodiversity. However, the long-term impacts of agricultural systems on below-ground biodiversity are not yet well understood.

Attention to these below-ground issues needs to accompany the above-ground efforts to optimize their collective impacts on agricultural sustainability. While it was suggested that below-ground soil microbiome interactions and other biodiversity indicators have been under-examined, they remain essential elements in promoting environmental sustainability. The potential advantages of specific varieties for improving soil health remain unresolved. Nonetheless, the potential benefits of PBI, with respect to soil health (e.g., below-ground biodiversity, aggregate structure) was recognized as vitally important to research in order to establish these benefits in agricultural systems.

It was asserted that the complexities of technological innovation requires increasing collaborations between farmers and breeders for the effective application of new technologies in existing and emerging agricultural systems. Specifically, it was suggested that developing platforms for farmers to contribute (i.e., convey their needs and expertise) to the design and implementation of plant breeding programs will become increasingly critical. . The importance of increasing effective communication with consumers was also emphasized. Specifically, expanding educational activities focused on food production and including consumers in the development of public and private breeding endeavors was suggested and widely endorsed. Notably, it was mentioned that stakeholders within the plant breeding community initially assumed that gene editing for disease resistance would garner support from consumers, due to the fact that this application can support agricultural sustainability (e.g., herbicide/insecticide/pesticide reduction). However, without a baseline understanding of agricultural processes and practices, this correlation is unclear to many consumers. In addition to potential ecological contributions, PBI (e.g., gene editing) create opportunities for breeders to develop varieties with traits that are directly relevant to consumers (e.g., eliminate allergens). Communicating all of the above information was considered to be essential for enhancing the science-based understanding of new technologies among the public *writ large* and ultimately, to optimizing the sustainability of the entire food system (e.g., including the role of consumers).

The importance of identifying the most effective and appropriate applications of PBI was discussed. It was posited that scientists may be overlooking opportunities in gene editing by focusing its use upon simple traits. It was noted that gene editing may also be effective for supporting broader breeding programs focused on developing complex traits (i.e., in conjunction with other tools for genetic selection). The necessity of viewing PBI (e.g., gene editing) as complementary to traditional plant breeding practices, rather than as a replacement, was emphasized. Specifically, it was argued that combining newer PBI with existing techniques such as marker assisted and genomic selection can support greater compatibility between different types of agriculture and/or result in the emergence of new versions of agriculture.

Several participants stated that the European regulatory framework is not conducive toward the adoption of new PBI and may inhibit progress towards achieving urgent sustainability goals. More specifically, it was argued that regulation of technology and intellectual property rights need to enable technology use for SMEs and participatory breeding programs. It was posited that investments in non-biotechnological PBI currently involve less risk, due to regulatory uncertainties surrounding biotechnological PBI. It was asserted that the opportunity costs (e.g., economic, environmental, societal) of delaying investment in the research and development of need to be quantified. Multiple stakeholders asserted that adoption of new technologies have the potential to help address global food security, limited arable land, and negative environmental impacts resulting from climatic changes.

Position Paper One
Roles of Plant Breeding for Sustainable Agriculture and Food Systems**

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University of Göettingen, Göettingen, Germany

Summary

Plant breeding innovations are crucial for sustainable agricultural development and food security. In the past century, the development and use of new high-yielding crop varieties have helped to increase food production considerably, thus reducing hunger despite a rapidly rising global population. However, past models of agricultural intensification have also contributed to low crop diversity and environmental problems. Moreover, climate change poses additional threats for crop yields and production stability. New plant breeding technologies (NPBTs), including genetically modified organisms (GMOs) and gene-edited crops, offer large potentials to make farming more productive, diverse, environmentally friendly, and resilient through the development of a wide range of beneficial crop traits (e.g., pest resistance, tolerance to drought, heat, and soil salinity). Despite independent research confirming that crops developed with NPBTs are as safe for human health and the environment as conventionally bred crops, anti-biotech narratives have led to unnecessary regulatory hurdles which limit the approval and commercial application of useful technologies. European attitudes against the use of biotechnology have spread to other parts of the world (e.g., Africa, Asia) where improved farming technologies are urgently needed. Harnessing the potentials of NPBTs for sustainable development requires a more honest public discourse and science-based regulatory procedures.

Current Realities

During the past century, plant breeding, combined with irrigation and agrochemicals, has led to unprecedented yield growth in major cereals (e.g., wheat, rice, maize). While chronic hunger persists, the global proportion of hungry people declined from over 50% in the first half of the 20th century to around 9% today. However, this model of agricultural intensification has also contributed to negative environmental issues (e.g., pollution, biodiversity loss). Moreover, the strong focus on only select major cereals has slowed dietary diversification, such that micronutrient deficiencies are now a greater health concern than calorie deficiencies. Against this backdrop, climate change is already impacting agriculture in negative ways (e.g., crop failures due to droughts and floods). The frequency and severity of climate calamities will also likely increase in the decades ahead. Communities experiencing poverty in Africa and Asia are particularly vulnerable since many of them depend on agriculture for their livelihoods. Without new and better technologies, sustainable agriculture and food security cannot become a reality.

NPBTs, including GMOs and gene-edited crops, could be a game-changer in addressing these challenges. They could contribute to higher yields, lower use of chemical fertilizers and pesticides, better crop resilience to climate-related stresses, and more diverse and nutritious foods. However, NPBTs are not yet widely used and accepted. Many perceive GMOs with skepticism, largely due to advocacy that effectively shaped opinions against the use of biotechnology. Although 30 years of research have demonstrated that GMOs are safe, widespread public concerns about possible negative consequences are persistent. These concerns have led to safety regulations and approval procedures for GMOs that are much stricter and more politicized than those for any other agricultural technology. In the European Union (EU), existing GMO regulations also apply to gene-edited crops, effectively functioning as a ban. In other words, NPBTs, which could contribute greatly to sustainable development, are limited primarily due to false narratives and public misperceptions.

Scientifically Credible Approaches and Challenges

NPBTs are no panacea for making agriculture more sustainable. Other innovations (e.g., improved agronomic practices) are also required. NPBTs will not completely replace other breeding methods such as conventional methods that play an important role for developing locally adapted varieties. However, NPBTs add precision and speed to the development of specific desirable crop traits. Through relatively small and targeted changes in the plant genome, scientists have developed and tested a number of interesting crop traits (e.g., pest resistance, higher nitrogen use efficiency, tolerance to drought, heat, and soil salinity, higher micronutrient contents). Independent research shows that NPBT crops are as safe for human health and the environment as conventionally bred crops.

The first transgenic GMOs were commercially approved in the mid-1990s and have been grown by farmers in many countries since then. Most GMOs commercialized so far involve insect-resistance (IR) and herbicide-tolerance (HT) traits in crops such as maize, soybean, rapeseed, and cotton. IR and HT crops have led to higher yields and incomes for farmers, even though other effects tend to vary by trait. IR crops have helped to reduce insecticide sprays, whereas HT crops have led to increases in the use of herbicides as a substitute for soil tillage. Another difference is that HT crops are primarily used by large, mechanized farms, while IR crops are used by all types of farms, including smallholders. Specifically, IR cotton has contributed to poverty reduction and improved livelihoods among farmers in China, India, Pakistan, and South Africa. Hence, it is not the breeding method as such, but the specific crop trait that determines technological effects and suitability for different situations. Proper technology policies and public support need to ensure that traits advancing sustainability are developed and used.

While recognizing the documented economic, social, and environmental evidence supporting the benefits of GMOs, two practical issues deserve attention. First, the number of commercialized GMO crops and traits remains small and far behind initial expectations. Second, almost all available GMOs were commercialized by large multinational companies, fostering market concentration in some parts of the seed industry. However, neither of these issues are inherent to GMO technology. Rather, they are the result of costly overregulation. Regulatory hurdles and politicized approval procedures for GMOs have made the testing and commercialization so expensive and uncertain that only multinationals can afford to do so with a small number of crops and traits that have sufficient commercial potential. Many GMO crops have been developed and tested by various organizations but were never approved for commercial use because of unfounded claims of hypothetical risks. Examples include drought-tolerant or fungus- and virus-resistant rice, wheat, potatoes, or bananas. While such applications could be hugely beneficial, politicians often lack the will to endorse technologies that are widely perceived as risky, even though these technologies have been declared safe by risk assessment authorities. Overly precautious attitudes towards GMOs are not only observed in Europe, they have also spread to other parts of the world, especially to Africa and Asia.

Gene-editing methods are newer and more precise than previous gene-transfer technologies. Many gene-edited crops do not contain foreign DNA, which could help to reduce many public concerns related to transgenic GMOs. Gene editing is not only fast but also relatively cheap, which means that small companies and public laboratories can also use these methods to develop crop varieties with various new traits. The low costs also allow researchers to examine previously neglected species ('orphan crops'). More than 40 different crop species have already been gene-edited, including various cereals, fruits, vegetables, pulses, roots, and tubers. Hence, gene editing could help to increase diversity in agriculture and seed markets. If locally adapted crops and varieties with interesting new traits are also accessible and affordable for resource-poor farmers, and if these varieties are properly combined with good agronomy (e.g., crop rotations, integrated pest management), these crop varieties could contribute substantially to making agricultural production systems more nutritious and sustainable.

Unfortunately, many of the potential benefits of gene-edited crops have not materialized since activists opposing agricultural biotechnology continue to use negative narratives associated with transgenic GMOs to characterize gene-edited crops. This viewpoint has affected science-based policy making regarding NPBTs in the EU where gene-edited crops are regulated in the same way as transgenic GMOs. This regulatory environment does not only affect development and cultivation in the EU, but also imported gene-edited crops and foods that require labeling and government approval. These requirements can lead to serious trade disruptions and technological stagnation in many other world regions.

Like any transformative technology, NPBTs can be used to support positive and negative trends. Consequently, proper technology policies and management are needed to ensure that desirable outcomes materialize while undesirable ones are avoided. Entrenched prejudice against GMOs in some regions has led to a quasi-ban, stifling meaningful discussion about potentials, limitations, and required policy actions.

Evidence-Based Options and Actionable Next Steps

Plant breeding innovations are crucial for sustainable agricultural development and food security. NPBTs offer major potential benefits to make farming more productive, environmentally friendly, and climate smart. Communities experiencing poverty have the greatest potential to benefit. However, further development and use of NPBTs are obstructed by overregulation and widespread concerns about hypothetical risks.

- Society needs to nurture a more evidence-based debate about the benefits and risks of NBPTs, emphasizing scientifically credible results. Credible concerns need to be considered, but narratives that ignore scientific, evidence-based understanding need to be dismissed. Scientists need to play a key role in clarifying public misunderstanding and building new, evidence-based narratives. The mass media needs to emphasize nuanced scientific evidence and de-emphasize unsubstantiated claims.
- EU policymakers need to reform the GMO law and regulatory procedures. First, gene-edited crops that do not contain foreign DNA need to be exempted from the existing restrictions. Second, a new law that supersedes the existing GMO law needs to be developed, regulating the breeding

product (i.e., a crop with a new trait) instead of the breeding method. While breeding products may be associated with certain health or environmental risks, there is no indication that breeding methods bear any specific risks.

- Policymakers need to implement effective anti-trust policies to avert market power in the biotechnology and seed industries. Reforms in regulatory procedures will help to foster market competition. Policymakers also need to observe and manage other factors that can contribute to market concentration (e.g., the strength of patents on plant technologies).
- Policymakers need to make sufficient funding available for public research with NPBTs. Public organizations need to ensure that crop-trait combinations that are particularly useful for sustainability and nutrition but not of sufficient commercial interest for the private sector, are developed through public research or public-private partnership.
- Agricultural policy and development organizations need to ensure that suitable breeding innovations are widely accessible to all farmers at affordable prices (e.g., through public-private partnership) and that these innovations are properly integrated into local production systems. Breeding innovations need to be combined with good agronomic practices, including crop rotations and integrated pest management.

Reference

Qaim, M. (2020). Role of new plant breeding technologies for food security and sustainable agricultural development. *Applied Economic Perspectives and Policy* 42: 129-150.

***** A position paper prepared for presentation at the conference on Sustainable Agriculture: The Role of Plant Breeding Innovation, organized, facilitated, convened, and moderated by the Institute on Science for Global Policy (ISGP) with support from the American Seed Trade Association and Euroseeds.***

Debate One Summary

This not-for-attribution debate summary was prepared by the Institute on Science for Global Policy (ISGP) staff from an audio recording, and its transcription, of the debate of the position paper prepared and defended by Dr. Matin Qaim (see paper above and author biographical information in the Appendix). Dr. Qaim provided a 5-minute summary of his paper, and then actively engaged all conference participants throughout the remainder of the 60-minute session. This debate summary represents the best effort of the ISGP staff to accurately capture the comments and questions posed by all participants, as well as those responses offered by Dr. Qaim and other participants. Given the not-for-attribution format of the ISGP/SA-PBI conference, the views comprising this summary do not necessarily represent the views of Dr. Qaim. Rather, it is, and needs to be read as, an overview of the exchange of views and priorities, both in support of and opposition to the points articulated by Dr. Qaim.

Current Realities

Throughout the debate, it was widely acknowledged that crop improvements through new and existing plant breeding innovations (PBI) are important for improving the sustainability of productive agriculture systems. A significant reduction of global hunger during the 20th century was partially attributed to various previously successful plant breeding initiatives. By extension, plant breeding was also regarded as important for the continued provision of food and nutritional security in the context of an increasing global population, climate change, environmental degradation, and resource scarcity. Participants offered a range of statements regarding the degree to which PBI are required for the development of sustainable agriculture systems. In general, it was widely affirmed that different innovations in plant breeding are not a "silver bullet" for achieving sustainability, though some participants asserted that they are an essential component of broad systems approaches to sustainability.

In particular, the potential contributions and limitations of transgenic genetic modification and gene editing technologies were discussed extensively in the debate. Within this context, transgenic organisms were generally described as genetically modified organisms (GMO) and crops bred using non-transgenic forms of gene editing were generally identified separately as "gene-edited." Both were discussed as relevant PBI that can support agricultural sustainability. Though there are few examples of widely commercialized GMO and non-transgenic gene-edited crops, the approval and cultivation of Bacillus thuringiensis (Bt) eggplant in Bangladesh was offered as a real-world example that biotechnological breeding technologies can have positive impacts. It was further expressed that several other previous applications of genetic engineering in plant breeding have exhibited shortcomings (e.g., over-intensive cultivation, increased herbicide use) that need to be understood and avoided in future plant breeding applications.

It was generally acknowledged that the current production and commercialization of new crops developed with genetic engineering (e.g., both transgenic and non-transgenic) is both time-consuming and expensive, partially due to existing regulatory frameworks enforced in many countries/regions. Purportedly, this combination has led to market concentration among a small group of large multinational companies. It was asserted that the small number of GMO traits that developed in the private sector do not all necessarily improve agricultural sustainability. It was suggested that small and medium-sized enterprises (SME), which are negatively impacted by financial and market challenges associated with obtaining approval to develop and commercialize new varieties, are limited in their opportunities to contribute to a competitive, sustainable seed sector. Typically, SME focuses on research and development in other areas, as a result.

It was broadly agreed that policies and regulations pertaining to plant breeding techniques are largely influenced by public perception and overarching societal dialogues. The nuances of communication surrounding the development, use, and regulation of plant breeding emerged as a prolific theme throughout the debate. Multiple debaters voiced frustration that the societal dialogue on biotechnological approaches to plant breeding has continued to focus upon many of the same points for 30 years, while ignoring the evolution of current scientific and technological understanding. Perceived communication failures by various stakeholders were cited as causes for public polarization regarding biotechnological approaches. It was generally recognized that effective societal debates regarding biotechnology would benefit from improved communication, including scientists. It was posited that private sector stakeholders are largely responsible for the degradation of public confidence in biotechnological innovations, as the first commercial transgenic crops were introduced alongside marketing messages that focused on the benefits to the farmer, rather than on consumer and public benefits. Additionally, the use of data generated internally by companies that produce GMO crops to promote their safety led to distrust among the general public. It was asserted that the persistent public perception that genetically engineered crops are distinct from plants bred traditionally, and are therefore "unnatural", has significantly interfered with the broad acceptance of food obtained with PBI. Multiple participants asserted that biotechnological breeding techniques can be applicable to any agricultural system.

Some participants expressed concern that public perceptions often reflect the notion that biotechnology is synonymous with intensive conventional agriculture, rather than viewing biotechnology as a tool that can enhance other management approaches as well. It was asserted that this conflation dichotomizes sustainability options and obscures other potential agricultural methodologies. In general, it was suggested that there are opportunities to incorporate elements of various different methods and tools in agriculture (e.g., agroecology and gene editing) to produce sufficient food in a more sustainable manner (e.g., with reduced external inputs, greater biodiversity).

Scientifically Credible Approaches and Challenges

Several debaters, including proponents of PBI via genetic modification and gene editing, noted that future plant breeding initiatives need to overcome the setbacks and failures of several previous biotechnological plant breeding initiatives. Specifically, it was contended that the improper use of Bt corn and glyphosate-resistant crops, characterized by a failure to utilize crop rotation and/or integrated pest management. These failures respectively led to the proliferation of corn rootworm disease and the emergence of glyphosate tolerant weeds. Environmental issues (e.g., pollution, erosion, soil salinization) were attributed to the over-intensive cultivation of a limited range of crops and varieties. Furthermore, it was asserted that some decreases in overall crop diversity, partly due to the limited commercial application of biotechnology to a few cereal crops (e.g., maize, wheat, rice), has expanded environmental degradation (e.g., biodiversity loss, poor soil health) and contributed to nutritional insecurity (e.g., nutrient deficiencies, imbalanced diets).

Many of the identified shortcomings of the few commercialized GMO crops were highlighted as being specifically relevant to how the technology was applied, rather than to the technology itself. Throughout the debate, the lack of crop and trait variety among commercialized GMO crops was directly tied to interconnected challenges: regulatory hurdles and private sector priorities. Concerns with regulatory frameworks based on the technology used to grow a crop or variety ("process") rather than assessing the properties of an individual crop ("product") drew intense attention throughout the debate. It could be anticipated that a process-based regulatory system would evaluate a product differently than a product-focused regulatory system. Illustrative of this point is the question of whether the regulatory evaluation of a specific product produced by different processes (e.g., conventional plant breeding vs. gene editing) would reach the same conclusion.

It was proposed that it may be most effective to frame regulations under the Cartagena Protocol on Biosafety (CPB) because it has provisions for establishing regulatory exemptions situationally as opposed to revising the regulatory decisions as supported by existing European Union (E.U.) legislation. This approach would minimize the need for new legislation. Within this discussion, there was disagreement regarding whether product-based regulatory frameworks are compatible with the CPB, which permits individual signatories to accept or ban the trade of Living Modified Organisms in accordance with its precautionary approach. Although all E.U. members practice process-based regulation (e.g., European Court of Justice ruling on Case C-528/16 on gene editing), some CPB signatories employ product-based regulation. The legitimate applicability of the precautionary principle to both non-transgenic gene editing and transgenic technologies was questioned because of a perceived absence of inherent risk associated with their use. The importance of considering the "true risk" of a technology, based upon credible scientific evidence, in regulatory policy decisions was expressed.

Policies related to intellectual property rights (IPR) were also discussed. Market concentration in the seed industry was claimed to be exacerbated by overly broad patents and excessive IPR. The impact varies by country, as do IPR policies within different nations. Additionally, it was also noted that patents can negatively impact the ability of farmers and breeders to access and use new germplasm. As patents on new products or technologies are often considered to be incentives for research and development within the private sector, it was emphasized that options to support regulatory IPR structures that engender innovation and market competition while preventing market power concentration are important.

While many participants posited that the safety of genetic engineering (GE) technologies has been sufficiently supported by credible scientific information and that potential risks have been effectively refuted, it was widely acknowledged that the perception of risk persists within public *writ large*. The dependence of policymakers on citizen viewpoints emphasized the importance of holding scientifically credible dialogues with governmental, private sector, and citizen communities. It was asserted that many policymakers who acknowledge the benefits presented by agricultural biotechnologies are often unwilling to publicly support related policy decisions, often due to adamantly anti-biotechnology, public narratives. It was widely contended that, under these circumstances, the most effective influence on policy occurs when communication is focused on the public, rather than on policymakers.

The appearance of adverse effects from intensive agricultural practices (e.g., increased herbicide use on transgenic glyphosate-resistant varieties) underpins the public perception that the purported benefits of biotechnological PBI are unfulfilled. It was acknowledged that absence of confidence in information provided by the private sector continues to dominate the public distrust on the use of biotechnology in agriculture. Furthermore, narratives that characterize biotechnological applications in general as environmentally harmful, also contribute to public concerns that obscure the importance of evidence-based information substantiating the benefits of biotechnological applications, especially in agriculture. The public uncertainty concerning these countervailing viewpoints was thought to undermine public support and funding for each group.

Evidence-Based Options, Actionable Next Steps

If coupled with proper agronomic practices, it was broadly proposed that innovative plant breeding could be an effective pathway to addressing several aspects of sustainability including: (i) enhanced climate resilience, (ii) reduced fertilizer and pesticide use, (iv) improved crop yield, (iii) minimized land use, and (iv) augmented disease resistance. Resistance to fungi (e.g., *Fusarium* in banana plants, *Phytophthora* in potatoes) was identified as an important application of gene editing that has already been significantly developed, but not widely approved or implemented. Improved disease resistance and environmental resilience in tree crops (e.g., coffee, cocoa, nuts, oranges) were suggested as important targets for the application of gene editing, particularly when other breeding techniques may be too slow to effectively respond to new challenges before long-living (e.g., perennials, trees) plants die or require replanting.

The importance of employing sustainable agronomic practices (e.g., integrated pest management, crop rotations) when growing new and existing crops was strongly emphasized and was considered vital to the success of crops bred with PBI. It was suggested that targeted actions may be necessary to ensure that growers have the knowledge, capacity, and incentives to undertake agronomic practices that support sustainability outcomes. Proposed actions included investment in improved access to credible information, economic platforms, education through extension programs, and regulation (e.g., establishing minimum requirements for crop rotation).

It was observed that evidence gathered on the use of GMO and gene editing technologies in agriculture has continually indicated no inherent risks for the environment or human consumption. It was acknowledged, however, that these technologies may be utilized either responsibly or irresponsibly and, therefore, it was strongly proposed that regulations need to be applied individually to new crops and their traits.

While it was acknowledged that a wide range of options exist within the umbrella of IPR, it was asserted that alternatives to patenting may be desirable. If patenting a technology is relevant to specific IPR interests, it may be less appropriate to patent the products of that technology. Some European farmers have initiated dialogues focused on allowing patents to be issued on transgenic crops, but disallowing the issuance of patents on non-transgenic, gene-edited crops.

Accelerating the time-to-market was noted as a major incentive for developing and implementing PBI, especially if patent applications and grants supporting effective IPR are streamlined to establish competitive markets based on a wide range of marketable crops. Even in a competitive market, it was acknowledged that public sector research and investment validation remain instrumental in supporting plant breeding efforts. These factors are especially germane in financially limited markets found in impoverished regions where the introduction and development of crops consistent with the cultural, nutritional, and environmental priorities are critical.

Incorporating contextual understanding of public interests and desires in different regions into the plant breeding and product development process was also considered important for the acceptance of new products. Other traits that were identified as potentially appealing to the public in various regions included those that provide nutritional and health benefits (in regions where there are not already an abundance of nutritionally dense alternatives) and environmental benefits (e.g., reduced external inputs, reduced soil runoff, land-use efficiency).

Since credible scientific evidence is needed to accurately inform the public discourse regarding the safety of various breeding technologies, several options were noted as potentially effective for overcoming the persistent skepticism found in many communities. It was suggested that candid dialogues between subject-matter experts and stakeholders holding diverse views regarding PBI are essential to establishing mutually respected, science-based approaches. It is essential that these dialogues encompass all evidence-based options and that rational approaches are used to address all concerns, without creating dismissive environments. Central to these dialogues is a commitment to establishing long-term sustainability objectives relevant to PBI initiatives.

Long-term sustainability objectives were viewed to be largely consistent among stakeholders, including those who remain divided on issues related to the use of biotechnologies in plant breeding. It was emphasized that an integrated systems approach, focused on immediately recognizable, shared goals and challenges, is critical. These goals and challenges, encompassed by several of the United Nations Sustainable Development Goals (SDGs), include: Climate Action (Goal No. 13), Zero Hunger (e.g., nutritional security) (Goal No. 2), Responsible Production and Consumption (Goal No. 12), Decent Work and Economic Growth (e.g., sustainable livelihoods) (Goal No. 8), and Life on Land (Goal No. 15) (e.g., biodiversity, deforestation). Several stakeholders concluded that an evaluation of products, rather than an examination of processes, provides a more accurate understanding on which to base regulatory decisions, and is central to integrated systems approaches.

Position Paper Two
Systems-based Concepts for Innovative Organic Plant Breeding**

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Summary

The current food system is based on an industrialized agricultural model characterized by low crop diversity and a variety of negative side effects. In order to achieve sustainable food security for a growing population, intensification of agricultural production needs to be implemented using fewer external inputs and without expanding existing agricultural lands. Biodiversity conservation and plant breeding linked with organic (or agroecological) farming and multi-stakeholder participation at a local level are key for sustainable and resilient food systems to address the United Nations Sustainable Development Goals (UN SDG). Organic plant breeding is a holistic, value-based concept focused on breeding for diversity in the living organic soil and for nutritious, delicious food. Participatory plant breeding (PPB) contributes to genetic diversity, local adaptation, seed and food sovereignty, empowerment of farmers, and rural development. As such, organic and participatory breeding approaches have significant potential in supporting a transition toward healthy, locally adapted, and affordable diets. To effectively make such a transition, the participation of local stakeholders in decision making processes is of special importance. The effectiveness of multi-stakeholder approaches that link breeding to value chain actors has been demonstrated. However, up- and outscaling are needed to achieve a paradigm shift toward breeding for diversity. A systems-based breeding approach to support diversity, which considers the long-term societal and ecological benefits of breeding that extend beyond direct value chain interests, is required to address critical societal challenges for food security in the 21st century. These challenges impact food quality, societal justice, agrobiodiversity, and ecosystem services. Significant efforts are needed on global, regional, and national levels to create awareness and ultimately shift the attitudes of consumers, value chain actors, farmers, researchers, and policy makers.

Current Realities

Transitioning toward healthy, locally accessible, and affordable food for a growing world population without destroying natural resources is a major challenge for agriculture and society as a whole.

In the past, increases in food production have been achieved by industrializing and intensifying agriculture through the use of synthetic fertilizer and pesticides, irrigation, and plant breeding. Mechanization, as well as herbicide-resistant crops, promoted large-scale farming and monoculture. Negative side effects include significant biodiversity loss through rainforest deforestation and bog drainage, loss of soil fertility through erosion, salinification and desertification, pollution of water, air, and soil, and man-made greenhouse gas emissions exceeding planetary limits.

Although over 6,000 different crop species have been cultivated in humankind's history, current food production relies on fewer than 200 crops, and over 40% of daily calories are derived from only three crops (i.e., rice, wheat, maize). Farmer-selected and farm-saved seeds have been largely replaced by uniform varieties that are responsive to chemical inputs and broad geographic adaptation, resulting in significant reductions in the genetic diversity of cultivated crops in the 20th century. Plant breeding became increasingly specialized, privatized, and focused almost entirely on those major crops and hybrid development that could provide rapid return on investment. Food and seed markets are dominated by large multinational players with high market and political power, resulting in a homogenized food and agricultural system. Although it is theoretically possible to feed 8 billion people based on current agricultural production, due to the unequal distribution of and access to affordable food, 10% of the global population suffers from hunger, 2 billion people suffer from micronutrient deficiency, and 2 billion people suffer from obesity. Holistic approaches fostering a paradigm shift toward increased biodiversity, plant-based diets, and fair power distribution are needed to achieve resilient, sustainable food systems with the capacity to feed a population of 9.7 billion people in 2050 and avert rural depopulation (Frison et al., 2016).

Scientifically Credible Approaches and Challenges

Biodiversity and plant breeding linked with organic (or agroecological) farming and multistakeholder participation at a local level are critical to building sustainable and resilient food systems that effectively address several UN SDGs (e.g., No Poverty [1], Zero Hunger [2], Good Health [3], Gender Equality [5], Clean Water [6], Decent Work [8], Reduced Inequalities [10], Responsible Consumption and Production [12], Climate Action [13]).

Organic plant breeding is a holistic, value-based concept acknowledging the coevolution of humankind and crop plants. Organic breeders select for diversity in the living organic soil to foster resilient self-regulating (i.e., thriving with minimal external inputs) farming systems that provide nutritious, delicious food. This includes breeding a wide range of crop species for local adaptation to various growing systems and markets, and developing genetically diverse populations (e.g., composite cross populations (CCP) derived from complex crossings, evolutionary, or dynamic populations) (Chable et al., 2020). Organic plant breeding also encompasses breeding for mixed cropping, agroforestry, or variety mixtures to increase crop performance and resilience. The importance of selecting under organic farming conditions has been demonstrated for maize and wheat, and the close interaction between plant and soil microorganisms is scientifically supported by the plant holobiont theory (i.e., viewing a plant and its associated microbiome as a single ecological unit) which corresponds to the influence of the gut microbiome on human wellbeing.

An effective transition of the food system requires (i) the participation of local stakeholders in decision making processes and (ii) the formation of effective linkages between breeding, farming, and the entire value chain, including consumers. PPB contributes to genetic diversity, local adaptation, seed and food sovereignty, empowerment of farmers, and rural development. The DIVERSIFOOD project (funded by EU Horizon 2020) applied a multistakeholder approach to its work on embedding crop diversity and networking for local, high quality food systems. This multistakeholder approach allowed the project to incorporate ecological, technological, socioeconomic, and political aspects throughout the value chain. Evidence supporting the deployment of genetic resources of underutilized crops in farmers' fields, adoption of PPB, collective management of agrobiodiversity at a community level, and improved understanding of the functioning of local, short supply chains of biodiverse products emerged from the project (Chable et al., 2020). DIVERSIFOOD has connected farmer and citizen initiatives with researchers through a collective learning and innovation process to embed healthy, delicious local products into regional food chains. However, the upscaling such pilot programs remains challenging. Therefore, in designing the LIVESEED project, FiBL focused its efforts on scaling organic seed and plant breeding across Europe. LIVESEED involved 50 partners from 18 countries to address technical, regulatory, policy, societal, and economic realities impacting the implementation of organic breeding approaches. Lammerts van Bueren et al. (2018) developed a systems-based breeding concept that considers the long-term societal and ecological benefits of breeding that extend beyond direct value-chain interests to address the societal challenges of food security, safety and quality, food and seed sovereignty, social justice, agrobiodiversity, ecosystem services, and climate robustness (Figure 1).

Evidence-Based Options and Actionable Next Steps

To achieve the needed transition toward societally just, resilient, and sustainable food systems, an appreciation for the urgency of the current realities faced by 21st century societies, paired with action on all levels in accordance with the aforementioned systems-based breeding concept, is required:

- Global, regional, and national authorities and policy makers need to support local food production through breeding, seed production, farming, processing, and marketing, with particular attention to rural development to avert rural exodus. The overall social status of farmers needs to be improved by strengthening farmers' rights related to seed and improving their access to resources (e.g., seed, soil, clean water, financial credits). Egalitarian and environmentally focused policies which include consideration for social responsibility, circular economy, and true-cost accounting of food need to be developed and implemented. International organizations (e.g., IFAD, FAO, WFP) need to expand investment in open-source information and communications technology tools to improve the transparency and traceability of agrobiodiversity management and food systems.
- Universities and research institutes need to promote multistakeholder approaches and give higher priority to providing continual funding for projects with demonstrated impact. These institutions need to reward researchers for their involvement in transdisciplinary projects. Public institutes also need to conduct research on underutilized crops, breeding for diversity, and organic pest and disease management (including post-harvest losses). Researchers need to engage with farmers to explore and incorporate the significant experiential knowledge of farmers into their research.
- Regional and local governments need to invest in research to widen cultivated crop species, with the goal of broadening the basis of food systems and thereby reducing the risk of yield losses. Governments need to also invest in training and capacity building for farmers interested in in-situ conservation, cultivation, and processing of underutilized edible crop plants. Furthermore, regional and local governments need to support farmers in accessing local or regional markets. They need to also develop public education campaigns on the nutritional value of traditionally underutilized crops: for example, by engaging well-known chefs to provide

recipes and cooking classes. Doctors need to communicate the importance of a diversified, plant-based diet for human health in order to influence consumer behavior. Schools and kindergartens need to educate children about healthy diets, install school gardens which utilize harvests in school meals, and conduct training in the preparation of healthy food. Regional or local governments and the private sector (e.g., food industry, seed companies, foundations) need to invest in training and capacity building in PPB, cultivar testing, and seed production to empower farmers and rural communities with a special emphasis on women and youth.

- Value-chain actors need to meet regularly with consumers, farmers, and breeders to develop common vision on sustainable food systems and support for breeding initiatives. Farmers need to join forces to invest in training, infrastructure, and entrepreneurship. Consumers need to request information on origin, farming practice, and breeding method of food. Traders need to test food for pesticide residues and declare information regarding the nutritional value and ecological footprint of food products to enable consumers to make informed choices for a healthy and sustainable diet.

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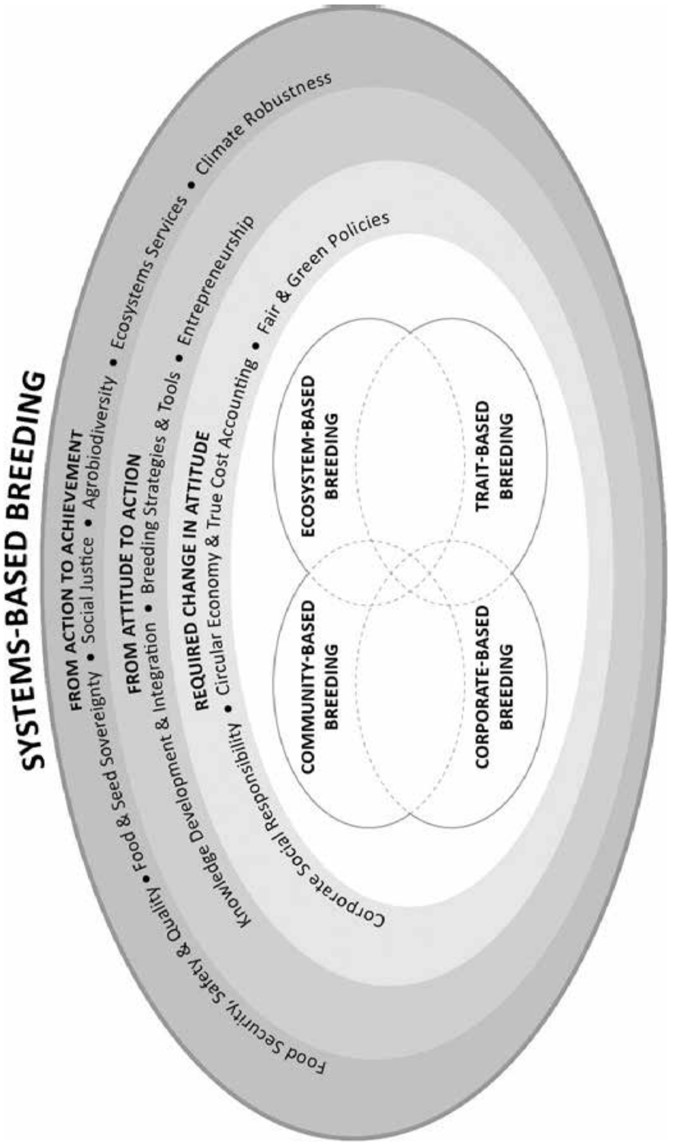

Figure 1. derived from Lammerts van Bueren, E.T., Struik, P.C., van Eekeren, N., and Nuijten, E. (2018). Towards resilience through systems-based plant breeding. A review. Agron. Sustain. Dev. 38(42). https://doi.org/10.1007/s13593-018-0522-6

For more information, refer to the LIVESEED homepage (www.liveseed.eu), and the following presentation from a 2019 LIVESEED workshop on Systems-Based Breeding: https://bit.ly/2HJmS6P.

Debate Two Summary

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Current Realities

There was broad agreement among participants with regard to the importance of common sustainability objectives in alignment with United Nations Sustainable Development Goals (SDGs); namely, to make agriculture systems (i) more environmentally responsible (e.g., through a reduction in the use of pesticide/fertilizer, biodiversity preservation), and (ii) adaptable to the impacts of rapid climate changes (e.g., improving disease, pest, and drought resistance). It was widely agreed that no single technology, methodology, or system of agricultural production is a panacea or "silver bullet" for achieving these established goals. It was, therefore, posited numerous times that agricultural sustainability requires a long-term focus on achieving coexistence among all approaches in ways that benefit all sectors and value chain actors equally. The views regarding the use of plant breeding innovations (PBI) held by the organic sector (i.e., producers, consumers, and breeders) diverge significantly from those held by stakeholders who support the broad adoption of genetic engineering (e.g., gene editing). This diversity of opinions was emphasized throughout the debate.

Specifically, it was asserted, and discussed at length, that the extensive opposition to the use of genetic engineering among many organic sector stakeholders often stems from the moral/ethical value placed on plants as living entities, rather than concerns about an inherent lack of safety or effectiveness associated with such approaches. Expressly, technologies that alter the plant genome at a subcellular level raise ethical concerns from some organic stakeholders due to the fact that a plant is able to reproduce from one cell. However, it was noted that many organic producers, consumers, and breeders do harbor concerns regarding the safety of gene editing. It was clearly expressed that these concerns need to be considered as valid and addressed respectfully within relevant discussions.

It was expressed that the organic sector is largely driven by consumer attitudes not only in opposition to gene editing, but in support of organic management practices (e.g., limiting pesticides/herbicides, promoting soil health/fertility). It was emphasized that many organic plant breeders and farmers (e.g., various apple and wine producers) have been developing improved varieties for 20-30 years by focusing on incorporating traits that enhance pest/disease resistance and stress tolerance. It was noted that this breeding knowledge within the organic community is valuable, and needs to be taken seriously and incorporated into discussions on coexistence. It was argued by organic sector stakeholders that many aspects of organic plant breeding can effectively support the development of sustainable agricultural models. For example, it was posited that by focusing on the use of diagnostic technologies (e.g., marker-assisted and genomic selection), the organic community supports the diversification of plant breeding methods used within agriculture, thereby strengthening the toolbox for responding to climate change impacts on agriculture. It was suggested that the systems-based approach of organic plant breeding can provide not only the widely recognized environmental benefits, but also enhance the societal equity in the economic sustainability of agriculture. It was posited that this can be achieved by emphasizing (i) farmer empowerment through participatory plant breeding (PPB), (ii) equitable distribution of market power, and (iii) effective ecologically supportive growing practices.

Scientifically Credible Approaches and Challenges

As the European Union (E.U.) strives to meet its Green Deal targets (e.g., reduced pesticide application), it is increasingly clear that the rapidity of climatic changes requires decisions that maintain acceptable crop yields. The incorporation of gene editing and other genetic engineering tools into organic breeding (e.g., to improve pest/disease resistance) was identified as a potential compromise among organic breeders and several non-organic stakeholders. It was asserted that organic stakeholders are open to plant breeding technologies while maintaining their previously identified ethical concerns (i.e., with regard to subcellular genetic modification). Therefore, issues related to the potential coexistence of organic and non-organic seed remained a prominent area of debate. One stakeholder, while in support of the E.U. Green Deal target to increase the total percentage of agricultural land under organic farming to 25% by 2030, noted that the presence of European organic certification requirements and the absence of European coexistence rules have limited advances in non-organic agriculture. It was widely agreed that any future coexistence rules need to facilitate equal opportunity for the development of both organic and non-organic agriculture.

Several participants argued that organic sector acceptance of low-level seed contamination is a scientifically safe, currently feasible, and effective pathway to promote coexistence. It was contended that since all seed/crop production requires variety separation, breeders are equipped to manage phytosanitary issues. However, concerns were raised regarding the feasibility of keeping contamination consistently below 1% (the cap for food to be certified in Europe as organic). Specifically, two key challenges associated with organic seed contamination were identified: (i) the economic burden of testing for the presence of genetically engineered (GE) material in each new generation and (ii) the inability to certify products as organic when contamination levels exceed 0.9%. It was noted that these risks may become increasingly difficult to manage if gene editing is broadly adopted prior to the development and widespread use of genetic detection tools. Considering these realities, participants noted the organic sector's strong support for regulation requiring the declaration of technology use in all agricultural sectors.

The minimization of pesticide use was identified as a means of achieving the broadly agreed upon aim to preserve and improve ecosystem health. As such, it was argued that both CRISPR (i.e., through the creation of pest resistant varieties) and organic production methods can serve as pathways to achieving this goal. Moreover, the compatibility of gene editing and agroecological methods was raised and supported as a potentially effective approach to enhancing agricultural sustainability. However, it was repeatedly asserted that gene editing is overemphasized as the sole method of effectively creating improved crop varieties.

While the point was raised that hybrid plant breeding and the benefits of hybrid heterosis (e.g., higher productivity, greater resilience to climate stress and disease) have been well documented, it was argued that the majority of organic plant breeders, particularly within Europe, prefer open-pollinated (OP) varieties. Particular benefits associated with the development of OP varieties through PPB approaches were cited: (i) preserving farmer ability to save seed and (ii) contributing to higher overall crop diversity and local adaptation within the food system. These issues were viewed as increasing resilience to climate change. In contrast, it was noted that while select United States (U.S). farmers may prefer OP varieties, there is not significant opposition in the U.S. to the inclusion of hybrid technology within organic systems. It was noted that the transatlantic divergence over the inclusion of hybrid technology within organic systems may relate to the wide accessibility of crop parental lineage within the U.S. where a large majority of hybrid development occurs at universities/public institutions. This structure has optimized the ability to trace and confirm the organic status of parental lines. The historical European development of organic plant breeding, led by the private sector, resulted in lower accessibility to identifying parental lines. Furthermore, as organic plant breeding in Europe was mainly led by biodynamic farmers, the European organic sector as a whole fostered particularly strong values regarding the purity of organic varieties.

Evidence-Based Options and Actionable Next Steps

Many participants recognized the role of organic plant breeding experts and innovators in contributing to the development of sustainable agriculture systems that are characterized by a plurality of solutions with which to respond to climate change. Nonetheless, it was recognized that organic farming systems typically produce lower yields due to the challenges agrobiological systems have in reaching the nitrogen levels associated with the yields found within conventional systems. For organic farming systems to be competitive and sustainable without the use of fertilizer and/or synthetic pesticides, an increased use of compost to improve soil fertility and/or legume rotation for increased soil nitrogen was recommended. Innovations in organic plant breeding were also noted as critical, with special attention to breeding for mixed-cropping, agroforestry systems, and plant-root microbiome interactions. All of these methodologies are expected to increase crop diversity, yield stability, and overall productivity within organic agriculture.

Working to expand connections, conversations, and alignment among different subject-matter experts and stakeholders along the food value chain (e.g., plant breeders, farmers, food companies, consumers) was repeatedly noted as essential to achieving sustainability goals within agriculture. While there was broad agreement that current non-organic and organic food systems involve engagement among stakeholders throughout the entire food system (e.g., producers grow crops at the request of food companies, consumers make purchasing decisions), participants strongly agreed that expanded public outreach and education regarding the value of emerging agricultural practices and technologies may help to enable sustainable agriculture. It was asserted that expanded consumer understanding of food systems with regard to production methods, seasonality of crops, and the importance of diversity in the food system (i.e., in the context of climate change) may increase public demand for diverse foods and support for regional adaptation. Specifically, participants suggested: (i) inviting consumers to connect with farmers in the field, engage in planting activities, and learn about the science of plant breeding (e.g., diversity within breeding material, timeline of breeding processes, the necessity of plant breeding for pest and disease resistance as the climate is changing) and (ii) involving local stakeholders in decision-making processes (e.g., city-level debates) to determine regional food system preferences. It was expressed that commitments to such efforts would sustain discussions concerning the practicality of actions for establishing sustainable food systems, rather than a focus on debates surrounding specific technology uses. Additionally, several stakeholders recognized the importance of providing diverse consumer food choices and preserving flexibility in the farmer decisions on production systems as new technologies allow for further development of novel products.

The mutual benefit of including farmers' knowledge of relevant traits and desirable breeding targets in the development of varieties through PPB was emphasized. Expanding the scale of PPB applications to increase options for the selection of regionally adapted varieties was a critical element in support of farmers. Several specific actions were identified: (i) taking full advantage of new EU regulation accepting organic heterogeneous material and (ii) implementing on-farm variety testing around the world, focused on yield data for different varieties. Concerning the latter, it was asserted that comparing this data alongside climatic and agroecological information can ultimately help farmers better choose which variety to grow under which regional conditions. It was also noted that capacity building through linking rural farmers to markets serving urban-area markets and citizens worldwide is especially critical in developing countries.

Proposed decisions concerning how to establish mutually beneficial coexistence among different agricultural production systems were discussed: (i) regional separation using the demarcation of agricultural regions (e.g., GMO vs. GMO-free) and (ii) cost-sharing agreements for contamination analysis. Supporting and participating in collaborative platforms focused on identifying (i) common goals shared by all value chain actors and (ii) the actionable decisions required to implement agreements was noted as fundamentally important to the future of sustainable agriculture. The importance of balancing acceptance of technologies with the swiftness of climate change and its impacts on the future of agriculture was also emphasized.

Position Paper Three
Plant Breeding Innovation for Sustainability**

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Summary

Agriculture is being called upon to produce more from less land, with minimal environmental degradation, and to provide land for other ecosystem services. These competing goals require the most effective plant breeding strategies. Genetically modified organisms (GMOs) in broad acre row crops have been incredibly successful in reducing insecticide use and increasing soil carbon sequestration. However, concerns about their inherent safety and ecological impact have led to opposition from some consumers and governments. This opposition slows the contribution of plant breeding innovation in making agricultural systems environmentally sustainable as well as more productive in terms of calories, nutrition, fuel, and fiber.

The foundations of the long-standing opposing views on GMOs are being eroded by new understandings of plant genomes, by lost opportunity from limited use of GM technology, by expanding possibilities created by new technologies, and by a recognition that innovation in plant breeding is required to manage the critical ecological and human challenges society faces. A suite of technologies create a spectrum of agricultural innovation from old-fashioned plant breeding to cutting-edge gene editing. Broad societal license and appropriate regulatory structure are needed if society and the environment are to benefit. Importantly, while there are real disagreements about which technologies are appropriate in plant breeding, there is overwhelming agreement on the desired outcomes for health, nutrition, safety, and environmental sustainability.

Current Realities

Changes in agriculture are critically needed to address the Sustainable Development Goals (SDG) of Zero Hunger (2), Good Health and Wellbeing (3), and Climate Action (13), and are foundational to most other SDGs as well. There are three important realities to consider regarding sustainable agriculture and plant breeding innovation: (i) agriculture has a critical role to play in contributing to positive, rather than negative, environmental impacts, (ii) agriculture needs to feed a growing population under changing climatic conditions, and (iii) for food companies to simultaneously deliver safe, delicious, nutritionally superior, and sustainable products, the small number of crop species we depend upon, and the even smaller number that has benefited from the full range of plant breeding tools, needs to dramatically increase.

For agricultural systems to be sustainable, they need to consume fewer resources, cause less environmental impact, and sequester more carbon per unit of the nutrition, energy, and fiber it produces. Reducing greenhouse gas (GHG) emissions across all sectors, and in agriculture (which accounts for approximately 11% globally), is a critical aspect of ensuring planetary sustainability. The Intergovernmental Panel on Climate Change (IPCC) estimates that to meet even modest GHG reduction goals, mitigation scenarios demand that an increase in land used for energy crops and forests must occur mainly at the expense of agricultural land for food and feed production. Agriculture is already struggling to meet societal needs within its current footprint but must reduce and adjust that allocation in the future. Plant breeding innovation can help reduce the GHG footprint of agriculture by (i) increasing productivity and (ii) sequestering carbon through greater use of cover crops and development of increased root biomass.

In the face of these challenges, agricultural production needs to also serve a growing world population, where malnutrition is already the leading cause of disease and death. Accelerating climate change means agriculture needs to do this while adapting quickly to new pests, diseases, temperatures, soil types, water availability, and changes in day lengths. The severe weather, temperature changes, and horrific fires of the last few years strengthen our understanding on the speed with which these changes are occurring. Thus, innovation in plant breeding is crucial and needs to accelerate. Unfortunately, developing new varieties that are responsive to climate change can take years in annual crops and decades in long-lived perennials. Many fruits and nuts, as well as crops such as coffee and cocoa, fall into this latter category. Many of these crops have breeding systems and genetic structures that make many conventional plant breeding strategies difficult and impractical within the timeline required to address current and anticipated human and environmental challenges. For example, many perennial crops do not tolerate the backcrossing that is often used for trait incorporation in annual crops.

Scientifically Credible Approaches and Challenges

It is estimated that just nine crops supply 75% of global plant-derived calories and just three (rice, wheat, and maize) account for approximately half. These crops are the superstars of agriculture since they are globally adapted, high yielding, and use efficient planting and harvesting methods. These three crops have dramatically reduced hunger and malnutrition. However, a future in which agriculture is more sustainable and contributes to the SDGs requires a diverse mix of well-adapted and highly productive crops. Such crops need to provide calories and protein but also nutrition, flavor, food safety, fiber, and energy. Concurrently, they also need to be affordable and accessible to a broad range of consumers. To achieve these goals, the agricultural community needs crops that will produce successfully in the diverse and modified environments that climate change is already creating. For example, because the IPCC suggests that forested areas will need to increase to meet climate change goals, crops that will thrive in agroforestry systems will become increasingly important. Agroforestry systems typically involve trees, shrubs, crops, and/or livestock. Many of those crops are vegetatively propagated (e.g., cassava, banana, various tree and vine crops). Some of these crops (e.g., banana) do not have a sexual reproductive phase, and would therefore, substantially benefit from gene editing approaches. There is considerable opportunity to improve productivity in these crop systems (e.g., agroforestry settings, perennial crops) through plant breeding innovation. To date, significant global commercial use of GMOs occurs only in corn, soybeans, oilseed rape, and cotton.

As gene sequencing technology has evolved, it has become scientifically clear that plant genomes are highly tolerant of genomic variation. Concern over induced genetic variation from plant breeding innovations often implies that cells and genomes are static in nature and that deletion, insertion, and rearrangement in the genome should be avoided and are inherently dangerous. This view of crop plant genomes is not supported by scientific evidence, nor by the incredibly safe history of plant breeding. It is not scientifically credible to ascribe risk to modern plant breeding techniques that do not change genomes in ways that are different from the changes continuously occurring during plant breeding, growth, and development. In fact, there are no documented examples in plant breeding in which changes that mimic nature have led to the production of novel toxins, allergens, or otherwise undefined novel risk.

Based on use, acceptance, and regulation, modern plant breeding techniques can be broadly grouped into four categories: (i) *technologies that allow breeders to predict, track, and select desired genotypes* (e.g., marker assisted selection, genomic selection, breeding values): powerful innovations used widely and accepted without significant regulation, (ii) *cellular biology protocols* (e.g., embryo rescue, cell fusion, doubled haploids) and *induced mutagenesis techniques*: innovations with long histories of safe use and a lack of significant pre-market regulation, prohibited or threatened by certain market segments (e.g., organic), but exempted based upon historical safe use from the European Union (EU) GMO Directive, (iii) *precision* *induced variation techniques* (e.g., gene editing, base editing, expression variation, RNAi, induced recombination): innovations with opportunities for wide use, but currently hindered by uneven and/or uncertain regulation and specialty market acceptance, (iv) *traditional GMOs* (i.e., transgenics): technologies widely used on a very small group of broad acre crops that have well-defined and cost prohibitive pre-market regulatory processes and consumer acceptance challenges that substantially exclude use in most crops and traits.

Evidence-Based Options and Actionable Next Steps

Food companies face a dilemma. Consumers expect food safety and quality and demand their food is produced in societally responsible and sustainable ways. Companies work diligently to ensure safety, use quality ingredients, and importantly, to address environmental concerns (e.g., by setting targets around GHG emission reductions). Agriculture production (which usually occurs outside the company) can be a significant part of the GHG footprint of a food company. Plant breeding innovations, which are vital to meeting sustainability goals in agriculture, at the same time cause concern about safety and environmental consequences for some consumers.

- The food industry needs to provide consumers with a level of transparency that meets expectations, yet does not confuse consumers and thereby reduce the opportunity to use science-based best practices to provide safe, affordable, and nutritious food produced in sustainable and increasingly regenerative ways.
- Non-governmental organizations, governmental organizations, and private sector companies need to develop, deploy, predict, track, and select plant breeding technologies across a broader range of plant species. These technologies (e.g., marker assisted breeding, genomic selection) are powerful and have broad acceptance.
- Governmental, private sector, and civil society stakeholders who are committed to sustainable agriculture need to work together to support scientifically credible routes to crop improvement by working together to identify shared desired outcomes. Attention needs to be given to unique challenges of "specialty" and vegetatively propagated crops, as these have great potential to meet nutritional and ecological goals.
- The global sustainable development community, the food supply chain, and governments need to support the development of a consistent science-based regulatory environment to enable the use of gene editing techniques

in food ingredients by establishing coalitions targeting the most critical agricultural sustainability problems and identifying multilateral solutions.

- The United States and EU need to seek a consistent regulatory environment for products developed using newer plant breeding technologies and a simpler regulatory path for GMO traits which have well-understood safety and efficacy. This kind of regulatory environment would remove one of the most significant barriers to innovation, particularly in smaller footprint crops in which the ability to economically support breeding innovation depends upon working with and deploying new varieties in many countries.
- Due to evolving scientific evidence, the EU needs to regularly review the risk management approach in the GMO Directive. Furthermore, in light of the European Court of Justice decision subjecting gene-edited crops to the same stringent regulations as conventional GMOs, the EU needs to either revise the GMO Directive to adopt a more proportionate risk management approach or create a "lex specialis" exempting gene editing techniques.

*****A position paper prepared for presentation at the conference on Sustainable Agriculture: The Role of Plant Breeding Innovation, organized, facilitated, moderated, and convened by the Institute on Science for Global Policy (ISGP) with support from the American Seed Trade Association and Euroseeds.***

Debate Three Summary

This not-for-attribution debate summary was prepared by the Institute on Science for Global Policy (ISGP) staff from an audio recording, and its transcription, of the debate of the position paper prepared and defended by Dr. Carl M. Jones (see paper above and author biographical information in the Appendix). Dr. Jones provided a 5-minute summary of his paper, and then actively engaged all conference participants throughout the remainder of the 60-minute session. This debate summary represents the best effort of the ISGP staff to accurately capture the comments and questions posed by all participants, as well as those responses offered by Dr. Jones and other participants. Given the not-for-attribution format of the ISGP/SA-PBI conference, the views comprising this summary do not necessarily represent the views of Dr. Jones. Rather, it is, and needs to be read as, an overview of the exchange of views and priorities, both in support of and opposition to the points articulated by Dr. Jones.

Current Realities

Throughout the debate, multiple participants recognized that addressing key societal and regulatory elements is important to advancing the use of plant breeding innovations (PBI) in sustainable agriculture. It was widely expressed that it is crucial to address (i) consumer acceptance of PBI (i.e., through customer interface activities that promote transparency and account for diverse consumer values), (ii) regulation of PBI by evaluation of specific products versus processes with particular attention to gene editing, and (iii) the flexibility provided to smallholder farmers in selecting the PBI best suited to their specific ecological and socioeconomic needs. Participants agreed on specific goals (e.g., sustainability, nutritional security, improved labor conditions) needed to effectively identify priorities and practical actions required for real-world decisions concerning existing and emerging PBI. While recognizing the diversity of viewpoints and priorities among participants related to some PBI, it was agreed that practical, science-based approaches required to reach aspirational goals need to be developed within the context of immediate local, regional, and global challenges (e.g., climatic, nutritional, humanitarian).

Improving consumer understanding of the proposed benefits and potential risks associated with new and historically contentious PBI (e.g., genetic modification, gene editing) was generally considered a priority. Many participants viewed improving consumer trust in the science underpinning food systems as an urgent need that can assist consumers in making informed food decisions based on scientifically-credible information. While the distribution of responsibilities for educating consumers was frequently revisited throughout the debate, the focus remained on the role of consumer-facing food retailers. The accuracy, transparency, and validity of food product labels was repeatedly discussed as a critical element in consumer interface activities. Misleading labeling used primarily for marketing purposes was viewed by many participants to be a major impingement in building science-based consumer trust and product acceptance. These concerns extended to both voluntary and legally required labeling, especially when characterizing the technologies (i.e., processes) used to produce a variety, rather than the food item (i.e., product) and its traits. Several participants asserted that process-based labeling does not convey useful information regarding the proposed benefits and potential risks of a product and places an unnecessary and misleading emphasis on the technology involved. The importance of separating process- and product-based evaluations was relevant throughout the debate.

Concern was expressed over whether non-transgenic gene-edited crops need to continue to be regulated to the same degree as transgenic organisms, particularly in the European Union (E.U.). Numerous participants contended that the beneficial application of PBI (e.g., on orphan and specialty crops) is being hindered by overregulation that unnecessarily categorizes a wide range of breeding methodologies into a single regulatory framework. It was acknowledged that global regulatory asymmetry leads to compliance challenges which were posited to be a barrier to technology adoption throughout food and agricultural supply chains.

Access by smallholder farmers to the PBI products (e.g., crop varieties) and farmers' freedom to select the tools and methods best suited to their particular circumstances was discussed extensively. The comparative advantages of large industrial producers was noted to be a prominent challenge for smallholders. Multiple participants repeatedly expressed their concern that large corporations and developed countries often make decisions about plant breeding methods and crops for smallholder farmers around the world, rather than involving smallholders in the development of crop varieties. The autonomy of farmers to choose which innovations suit their unique ecological and socioeconomic needs was strongly supported by the majority of participants.

Participants considered the merits and limitations of coexistence as applied to the organic and non-organic sectors and their respective agricultural markets. As defined by the United States Department of Agriculture (USDA), "*coexistence refers to the concurrent cultivation of conventional, organic, IP, and genetically engineered (GE) crops consistent with underlying consumer preferences and farmer choices. Farmers and others in the food and feed production chain have an important role in collaborating* *to make coexistence work, particularly in the areas of stewardship, contracting and attention to gene flow.*" Diverse levels of support for the concept of coexistence were expressed, especially with respect to the degree of flexibility different points of the value chain have in accessing both organic and non-organic tools without requiring the exclusive adoption of either.

The grounds on which the organic sector rejects certain plant breeding technologies was questioned. One participant argued the indivisibility of the cell is not a biologically sound reason for the rejection of new technologies, as traditional plant breeding also depends on the natural divisibility of the cell in meiosis and recombination. It was noted that these rejections are made based on values, not necessarily the projected risk of technologies, and does allow for adoption of certain technologies (e.g., double haploids). It was proposed that preserving organic germplasm in the future is a core challenge for achieving coexistence.

Scientifically Credible Approaches and Challenges

It was widely recognized that consumer-facing companies have a challenging and crucial responsibility to provide accurate, science-based information to consumers. Misleading labeling used for marketing purposes was identified as a key issue to ensuring consumer confidence. It was noted that the use of non-GMO labels on a product for which there is no GMO alternative (e.g., vinegar, water) is misleading and contributes to the consumer distrust in GMO as well as other PBI products that may have been grouped with GMO in regulations. Debaters contended that prominent anti-biotechnology narratives delay and hinder the development/implementation of multiple PBI technologies and postpone their potential benefits to consumers. A question was raised on whether such third-party labeling certifications need to be collectively denounced. It was recognized that scientists have a responsibility to provide accurate, science-based information to consumers. However, this was viewed as a challenge, as some participants felt that companies have an obligation to disclose science-based information in response to consumer requests. While food retailers with broad public interface capabilities have an obligation to accurately inform consumers using scientifically-credible information, the often-encountered distrust among consumers in the private sector was recognized as making these responsibilities challenging. Nonetheless, it was recognized that food companies need to address the evolving values of consumers, especially with respect to PBI. It was posited that despite consumer concern regarding biodiversity, the understanding of how biodiversity relates to sustainable agricultural practices and the use of PBI is often incomplete.

Many participants viewed the grouping of multiple different PBI technologies under the same regulations as inappropriate based on current scientific understandings. Some participants agreed that certain GMO products fail to meet the criteria for rejection by the "Precautionary Principle" based on their well-understood safety and efficacy. Likewise, many participants agreed that precision techniques (e.g., gene editing, base editing, expression variation, RNAi, induced recombination) also merit exemption when used to produce varieties with traits that have been, or could be, achieved in varieties bred using widely accepted breeding methods. It was clarified that these proponents also supported regulation in areas they deemed appropriate, primarily for novel traits.

Though the appropriate level of PBI regulation was a point of contention among participants, it was recognized that country-to-country regulatory asymmetry presents significant challenges to broader adoption of PBI. While many participants generally supported coexistence, ensuring the effective isolation of supply chains was viewed as a critical challenge. The USDA Sustainable, Ecological, Consistent, Uniform, Responsible, Efficient (SECURE) Rule to Regulate Agricultural Biotechnology was proposed to be one example of the complex challenges associated with ensuring consistency and compliance within international food markets. The SECURE rule would allow certain gene edited products produced in the U.S. to be self-certified by a producer and avoid certain regulatory processes. Given the wide-ranging policy frameworks across international markets, it was noted that even food companies that are compliant with the SECURE Rule could unknowingly break the law if their PBI products enter the supply chain in a country with stricter regulations.

It was recognized that smallholder farmers are directly impacted by the diverse regulatory environments globally, as they strive to grow varieties that are compatible with their ecosystem, as well as the markets they wish to serve. It was proposed that increasing agricultural productivity will enhance the economic viability of smallholder farms worldwide. It was asserted that this can only be the case if the appropriate traits and varieties are accessible to farmers through equitable distribution of the benefits of PBI. It was posited that fruits and vegetables are essential to nutritional security, but that smallholder farmers experience major challenges (e.g., viral and fungal disease vulnerability, post-harvest waste and loss) producing these crops. PBI that can target traits that address these challenges were proposed as a potential solution. Marker assisted selection of a *Phytophthora* resistance trait in pepper varieties distributed to numerous smallholder farmers in India was cited as an example of the benefits PBI have delivered to smallholders. Development of crop varieties suitable for mechanized agriculture was noted as an underappreciated benefit for smallholders as well. When discussing the future development of PBI, participants focused on traits promoting sustainability. Encouraging carbon markets through the development of varieties for carbon sequestration was presented as another current scientific approach by one participant. However, it was noted that, while paying farmers for their environmental services is a potentially promising option, and one to which a variety of PBI could contribute, there are currently challenges in obtaining accurate assessments of carbon storage and output that hinder the effectiveness of efforts focused on achieving carbon neutrality and providing ecosystem services in agriculture (e.g., via "carbon farming" markets).

Evidence-Based Options and Actionable Next Steps

Participants contended that there are not only many potential benefits (e.g., sustainability, nutrition, economic prosperity, equitable human working conditions) to the use of PBI, but that there are both social and ecological costs associated with delayed research, development, and implementation of related technologies. It was widely posited that the urgency of adapting to climate change, ensuring nutritional security for a growing global population, achieving equitable opportunities for smallholder farmers, and responsible working conditions for agricultural laborers are all priority issues that could be addressed by using PBI. The importance of balancing the "Precautionary" and "Innovation" Principles, was proposed as essential in effectively evaluating the contributions of PBI to sustainable agriculture.

It was suggested that regulation needs to be updated with a consideration for the practical contributions anticipated by the applications of PBI, especially with respect to addressing key sustainable development goals (SDG). Many, though not all, participants supported the simplification of existing E.U. regulatory standards for emerging PBI (e.g., gene editing, base editing, expression variation, RNAi, induced recombination) and some supported similar revisions for regulations pertaining to transgenics with well-understood safety and efficacy. The exemption of non-transgenic gene editing from regulation as a GMO was posited as an important policy revision. It was also widely proposed that the qualities of a product (i.e., novel traits) need to serve as the criteria for regulation, rather than the technology used to introduce specific traits into a variety. Such revisions were viewed by some participants as essential to the effective implementation of PBI to support sustainable agricultural practices. It was clarified that proponents for simplifying the PBI regulatory process also supported regulation in areas they deemed appropriate (e.g., for novel traits). Formation of a consistent regulatory framework between the E.U. and United States was posited as vitally important by a majority of participants.

The majority of participants posited that consumer understanding of PBI and the nuances of sustainability in food systems was a major concern. It was agreed that consumers require and deserve transparent information to support their food choices based on scientifically-credible information that is not misleading in its focus. When science contradicts information that is being conveyed to consumers, through labeling or other consumer interface activities, it was posited that scientists need to engage a discussion. Expanding and diversifying labeling to encompass more nuanced views on product attributes (e.g., sustainability, enhanced nutrition, improved labor conditions) was suggested. Initiation of dialogues that inform consumers on the benefits of products, while promoting a diverse and integrated agricultural system and technological tool kit, rather than a focus on the method of production itself, was suggested to be important. Taking advantage of new opportunities to engage consumers based on emerging e-commerce platforms was suggested. The use of e-commerce by consumer-facing retailers may also impact their responsibilities for providing traditional labeling.

The importance of making farming a more economically viable enterprise, especially for smallholders worldwide was strongly supported. Special attention needs to be given to PBI products or applications that provide the greatest potential advantages to smallholder farmers. Specific PBI applications that were proposed to provide the greatest benefit to smallholders included the development of varieties which: (i) combat fungal, viral, and microbial diseases (ii) enhance crop yield and reduce post-harvest loss, (iii) expand the use of underutilized crops and varieties, (iv) facilitate mechanized agriculture, (v) ensure ecosystem protections, (vi) enable ecosystem services (e.g., promote carbon sequestration and soil health), and (vii) enhance economic sustainability throughout farming communities. Participants also encouraged large food entities to utilize participatory plant breeding with the smallholders from which they source. Collectively, these activities were viewed as increasing the flexibility of farmers to select which crops, traits, and technologies best align with their specific geographic, cultural, ecological, and economic needs, as well as the marketplace priorities they wish to serve.

Position Paper Four
A New Generation of Plant Breeding for a Next Generation of Farmers**

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Summary
"Combining century-old traditions with the most recent innovations." This is the framework in which young farmers, across the world, want to produce and perform. Throughout their lifetimes, farmers are faced with a unique set of circumstances, challenges, capacities, and ambitions. All those factors create an endless pool of possibilities that enable the diversity in farming today. Any evolution, guided by policy, sector, or industry, needs to acknowledge and serve the diversity of farming systems. Farmers will only be able to do their part in enhancing environmental performance (while producing safe products) if provided with a palette of accessible interventions, instruments, and techniques. This will require the seed industry to ensure that farmers have access to a wide selection of crops suited for all kinds of realities. It will also require policymakers to create a regulatory environment that allows farmers to embrace the possibilities offered by a new generation of plant breeding.

Current Realities
In all its forms, plant breeding innovation is a topic discussed and debated all over the world. Such discussions provide valuable international references when it comes to evaluating the success or challenges of various innovations and creating opportunities to commonly invest in research, development, and implementation.

Misconceptions and a lack of knowledge regarding available technologies has often fueled this global debate, which is characterised by increasing polarization. Such polarization has led the European Union (EU) to use the precautionary principle as a veto for any reasonable conversation or evolution to take place. More importantly, the focus on terms, such as "Frankenstein food," in the global debate have undermined opportunities to discuss how to overcome the real challenges that plant breeding innovation can bring.

Separate from the often theoretical debate at global level, farmers evaluate opportunities within plant breeding in real terms (i.e., increased efficiency and yields, improved pest management, resilience to changing weather patterns). However, farmers also experience on-farm difficulties first-hand, in terms of implementation. All innovations have prerequisites in terms of knowledge, which need to be presented in a way that places the interest of farmers at the center. In this perspective, advice given with a commercial or ideological interest would prove counterproductive. Additionally, whether it requires additional investments or not, on-farm innovation is directly linked to the financial capacity of farmers to manage potential risks. Despite their natural aim to support further innovation, young farmers face limited capacity to invest in technologies or build resilience to risks. As a consequence, they are less likely to become "early adopters" of new practices or technologies that can help to improve on-farm environmental performance.

Due to the current costs of research and development (R&D) in plant breeding, only a small number of companies can gather the necessary knowledge and resources to provide farmers with seeds. Those companies often market a limited number of varieties. The low degree of competition, due to R&D cost barriers, combined with a stringent legal framework in the EU, does not encourage smaller players to enter the markets, with the result being detrimental to innovation itself.

Scientifically Credible Approaches and Challenges

When applying plant breeding innovation, efforts need to always be directed at increasing genetic diversity, rather than limiting such diversity. This implies that the seed industry needs to consider ways to ensure that (i) plant varieties currently available to farmers and to society remain available and (ii) new varieties become available in the future. To ensure this, the seed industry and public policy need to direct R&D investment into a diverse set of crops, rather than only those with a high uptake. In the long run, society also has a responsibility to provide market incentives for a broad range of crops through its consumption behaviours.

The need for genetic diversity also implies that a variety of seed producers and suppliers are needed to assure a wider range of options available to farmers. Within the current plant breeding policy framework (or lack of framework, when considering the EU), only a handful of players can utilize the most recent technology and implement innovations. Therefore, it is essential that public support for start-up innovation is provided. Ensuring that developments can be protected while remaining open for further use is equally important. The possibilities for strong limitations stemming from patent procedures must be reduced regarding plant breeding, allowing different players to continue innovating.

The existence of different strategies on the international stage, between countries that deploy offensive "wild west" politics and those that choose a more defensive approach, creates competitive disadvantages in global trade. When considering adopting these innovations, the most defensive regions (i.e., in terms of technology adoption) risk becoming dependent on the producers in regions that already have technologies on the market. Furthermore, while young farmers, in the European context, would welcome a more progressive stance on a next generation of plant breeding, such a dynamic would only be profitable to all stakeholders if it results in building bridges between domestic (EU) industries and the farming sector. If regional seed suppliers can develop domestic production at the same pace as farm uptake, suppliers would be better equipped to provide for the specific needs of a region as related to historical productions or processing industries.

The main threat that farmers face lies in the intent of the discussion. Any debate or evolution in the field of plant breeding risks being built on either commercial or ideological interests. However, what is required at this moment, is a debate focused on solving some of the most critical challenges (e.g., hunger, climate change, poverty). However frightening these global challenges are, they also form opportunities for innovation. The global recognition given by the Nobel Prize in Chemistry to the two developers of CRISPR-Cas9 is an encouraging signal that the world values the potential of plant breeding in facing major global challenges.

While in past decades plant breeding focused on increasing resilience and yields above ground, the future requires attention to additional possibilities, such as the crop-potential to sequester carbon in the soil. There is significant potential to improve sustainability by stimulating the root-growth of crops. If combined with effective management practices, these crops could not only store significant amounts of carbon in the soil, but also create further resilience to drought in fluctuating weather patterns. Additional attention on enabling farmers to increase their local protein production is needed, and can be achieved by (i) augmenting the protein levels in "common" crops (e.g., grasses) and (ii) developing high protein crops (e.g., soy) that can be better produced in a wider range of climate conditions.

Such innovations would assist a variety of farmers to increase environmental performance and contribute to climate change mitigation, both of which are consistent with the objectives put forward in the European Green Deal and the EU protein plan. They would also increase the positive response toward plant breeding in general. Implementation of these innovations on the farm level could be further incentivized by remunerating farmers via a carbon farming market or coupled support for protein production in the framework of the Common Agriculture Policy (CAP).

Evidence-Based Options and Actionable Next Steps

Plant breeding has a key role to play in answering to growing agricultural demands in the 21st century. However, to address the diversity of on-farm realities, needs, and markets, farmers need to be provided with a broader range of crops, varieties, seeds, and trading partners. Farmers everywhere operate in a global trade framework (either directly or indirectly) and are therefore impacted by trade relations between different countries. Thus, ensuring a level playing field by balancing domestic plant breeding policies among trading partners is necessary to ensure sustainable trade. All stakeholders need to work collectively to connect diverse markets that effectively support and incentivize innovation in the food system.

- Plant breeding innovation needs to increase diversity and not reduce it. Policymakers need to use every tool to ensure that farmers can freely rely on choices between different crops, varieties, seeds, and trading partners. Ensuring the availability of these options requires developing legal frameworks that empower both the seed industry and farmers to ensure fair competition across the world. Such policies would provide resources for public and private research institutions to invest in "less marketable" innovations and crops.
- Ensure a level playing field for the sake of international trade. Policymakers need to establish rules targeted at production standards of crops (e.g., with regard to the use of gene editing) and intellectual property using multilateral approaches. In particular, the domestic policy of the EU needs to acknowledge the potential advantages offered by a new generation of plant breeding. Trade policies need to strive towards ensuring that every farmer has access to the same products and processing opportunities within equivalent legislative environments.
- Explore the full potential of plant breeding innovation. Seed companies need to develop a new generation of crops that helps farmers increase the potential for climate mitigation at the farm level and/or enable local protein production. Specific breeding priorities that need to be pursued include increasing the carbon-catching potential of root systems, increasing the protein levels of crops, and/or improving the growing conditions of protein crops.
- Ensure a competitive environment for seed producers and sellers. Policymakers need to implement a regulatory framework that fosters research, development, and production, and enables the smaller players in

the seed industry to move forward in plant breeding, thus ensuring a wider range of options available at farm level.

- Follow market-driven development of food systems and crop varieties. All stakeholders within the food and agriculture supply chain need to coordinate efforts to ensure that farmers are provided with tailored and affordable seeds. Stakeholders in the food supply chain need to collaborate to provide the necessary innovations, knowledge, market information, and processing capacity for specific industries (e.g., biomass production, cereal production for human consumption).

*****A position paper prepared for presentation at the conference on Sustainable Agriculture: The Role of Plant Breeding Innovation, organized, facilitated, moderated, and convened by the Institute on Science for Global Policy (ISGP) with support from the American Seed Trade Association and Euroseeds.***

Debate Four Summary

This not-for-attribution debate summary was prepared by the Institute on Science for Global Policy (ISGP) staff from an audio recording, and its transcription, of the debate of the position paper prepared and defended by Mr. Jannes Maes (see paper above and author biographical information in the Appendix). Mr. Maes provided a 5-minute summary of his paper, and then actively engaged all conference participants throughout the remainder of the 60-minute session. This debate summary represents the best effort of the ISGP staff to accurately capture the comments and questions posed by all participants, as well as those responses offered by Mr. Maes and other participants. Given the not-for-attribution format of the ISGP/SA-PBI conference, the views comprising this summary do not necessarily represent the views of Mr. Maes. Rather, it is, and needs to be read as, an overview of the exchange of views and priorities, both in support of and opposition to the points articulated by Mr. Maes.

Current Realities

It was broadly recognized that the successful implementation of new technologies supporting plant breeding innovations (PBI) that promote sustainable agriculture is challenged by restrictions in existing regulatory frameworks, limitations to global market accessibility, and the complexity of interfacing with diverse crop and seed varieties. It was noted that as the impacts of existing and emerging climatic challenges appear, farmers may be able to make more effective contributions to climate mitigation and adaptation through the implementation of environmentally supportive practices (i.e., carbon sequestration and erosion resilience). In addition, farmers can provide a diverse array of crop varieties to address shifting local, regional, and global market demands. Both subject-matter experts and stakeholders actively engaged in analyzing, critiquing, and reconfiguring the many elements that comprise these topics as they developed potential actionable decisions supporting sustainable agricultural goals.

Generally, it was acknowledged that every farmer, practice, and technology has differing opportunities and capacities to support climate mitigation and adaptation, and that regionally specific carbon sequestration initiatives may be more successful than singular, widely implemented strategies. It was noted that many young farmers are eager to implement environmentally sustainable agricultural practices (e.g., carbon sequestration, decreased pesticide use, biodiversity preservation). Participants recognized that many of these practices can be implemented through the utilization of crop and seed varieties developed based on PBI. The diverse capabilities and priorities of individual farmers differently equip them in their efforts to provide ecosystem services. It was argued that differences in farmer capacity depend upon access to adequate financial resources and environmental limitations (e.g., local geographical characteristics). Regardless of these limitations, it was argued that every farmer needs to contribute to climate change mitigation and adaptation within the confines of available technology, arable land, and financial resources. It was widely endorsed that increasingly globalized agricultural markets will continue to influence how individual farmers determine which varieties and crops to produce, and which technologies to utilize in achieving their individual goals and/or the priorities identified within governmental frameworks (e.g., Farm to Fork in Europe).

The existing European Union (E.U.) regulatory framework was consistently identified as playing a critical role in determining the scale and scope of research, development, and implementation of PBI technology in Europe and among its trading partners. Specifically, it was asserted that the high costs associated with PBI have hindered its introduction into the agricultural system, the utilization of PBI varieties by farmers, and farmer marketplace participation and advancement. High PBI costs also limit market participation by small and medium enterprises (e.g., start-up innovators), leading to sustained market control by a small number of large multinational corporations. As globalization enhances the exchange of resources across national and international borders, it was recognized that E.U. policy influences not only domestic, but also transnational supply chains. These conditions were noted as contributing to limited product availability and diversity on a global scale. It was noted that the lack of standardization across global regulatory frameworks will increasingly challenge food systems. In particular, the use of PBI techniques (e.g., gene editing) is difficult to detect in traded products. It was continuously emphasized that the international demand for products bred with PBI technologies challenges E.U. farmers growing within the confines of the E.U. regulatory framework. The reality that small, first-generation, young farmers face barriers to marketplace participation (e.g., difficulties accessing land, financial incentives, and long-term partnerships) was identified as a critical challenge.

Within the context of unpredictable global circumstances and, specifically, the existing coronavirus pandemic, it was expressed that self-sufficiency, regional adaptation, and specialty crop production are increasingly necessary farming system characteristics for smallholders. However, the point was raised that this model contradicts the simultaneously unfolding narrative that farmers will receive significant economic benefits from increased involvement with non-specialty, commodity crop supply chains for mass global distribution. The understanding that the establishment of stable, thriving local economies necessarily precedes farmer participation in large global trade markets was challenged. While a shift in focus toward local endeavors may slightly diminish the pace and scope of global trade, it was contended that avenues to participate in local, regional, and globalized systems are critical for the economic resilience of farmers.

Scientifically Credible Approaches and Challenges

Broadly, it was argued that PBI offers significant opportunities to not only increase the technological choices available to farmers, but also the diversity of marketplace choices available to consumers. Given the large population of farmers worldwide, and their wide-ranging environmental, cultural, and economic contexts, many emphasized the need to respect and engage the attributes unique to individual farmers. These issues pertain especially to their use of land to expand the array of diverse products available to global consumers. It was noted that this type of approach may allow smallholder farmers to produce specialty products (e.g., organic, fruits, vegetables) to meet niche consumer demand, thereby positioning large acreage entities and multinational corporations to continue primary production of commodity crops at a mass scale. It was widely emphasized that as PBI continues to evolve, new technologies can be implemented in tandem with existing traditional (e.g., agroecological), organic, and conventional growing practices and methodologies rather than serving as replacements.

In discussing existing applications of PBI, it was noted that previous emphasis has been focused on improving above-ground traits and impacts (e.g., increased crop yield, improved pest resistance, reduced pesticide reduction). These applications enhance crop resilience, but also contribute to soil health, especially with respect to carbon sequestration. As scientific PBI advancements continue to emerge and become broadly available, many agreed that PBI needs to focus on improving below-ground traits (e.g., nitrogen content, microbial diversity, and carbon sequestration) to support the increasingly critical issue of soil health in agricultural sustainability.

The need to consider the impact of prioritizing ecologically supportive farming methods on overall crop yield was emphasized. The point that certain types of farming (e.g., livestock) have greater environmental costs than others was contended. Specifically, it was argued that the purported negative environmental impacts associated with livestock farming may be offset by the ability of pasture grass to sequester carbon. Future climate mitigation and adaptation efforts on the farm-level were broadly characterized by the recognition that individual farmers will be most efficient in addressing a single or few particular environmental issues (e.g., reduced pesticide use, air quality management, improved biodiversity) rather than providing all ecosystem services simultaneously.

As European farmers compete with farmers from regions with fewer restrictions on the use of PBI technology, it was indicated that it may become increasingly challenging to establish and secure a role in the marketplace without amending the E.U. regulatory framework. More specifically, it was expressed that farmers from less-regulated countries have an advantage because they are able to grow according to any and all consumer demands (e.g., conventional, GMO, organic). Regardless of the challenges presented by the E.U. regulatory framework to European farmers, it was widely agreed that an anticipated shift in consumer attitudes in favor of PBI has emerged alongside consistent and growing demand for non-genetically modified (GM) foods and ingredients. Questions were raised concerning the extent to which consumers currently embrace GM products. Current and anticipated consumer demand for a diversity of crop production styles was recognized as being able to sustain marketplace opportunities for farmers interested in implementing non-PBI farming techniques. However, concern about the initial feasibility of non-PBI products to establish and maintain market presence persisted. It was suggested that intentional, long-term private and public sector investments and outreach initiatives that support marketplace participation by farmers will be critical in influencing consumers.

It was noted that farmers often face conflicting priorities when determining whether to support the expanded utilization of PBI within the agricultural sector. Because many farmers rely heavily on public subsidies and corporate partners to sustain market presence, the point was raised that farmers often feel unable to express personal preference regarding the implementation of imported seeds and crop varieties produced via specific breeding methods (e.g., gene editing, transgenesis) that have been approved by other stakeholders within the international supply chain (e.g., U.S. market participants). The theme of diversity was similarly echoed in conversations regarding the need to expand marketplace participation and sources of revenue and/or incentives for first-generation farmers and start-ups. Specifically, the expansion of both public and private grants and subsidies for initial land acquisition was discussed. Because it was consistently expressed that initial access to arable land is an enormous barrier for young farmers in particular, subsidization of biotechnologies was noted as less imperative than land provision.

Evidence-Based Options and Actionable Next Steps

The broad recognition that farmers currently experience the most severe consequences of climate change and are, simultaneously, particularly well-positioned to serve as stewards of the land, characterized much of the debate. Increased collaboration among all agricultural stakeholders and deliberate advocacy on behalf of on-the-ground (e.g., PBI implementation) farming issues was widely supported. The advantage of continuous multi-stakeholder discussions, forums, and conferences (e.g., United Nations Food Systems Summit) was underscored numerous times. As future generations of farmers increasingly manage unpredictable climate patterns, evolving consumer demands, and novel PBI, it was acknowledged that new opportunities to address emerging global issues (e.g., protein deficiency) will become increasingly possible. Such opportunities require the consistent participation of all stakeholder groups.

It was broadly recognized that farmers are societally well-positioned and equipped to support the introduction of climate resilient crops and traits that are both (i) in global demand and (ii) provide local ecosystem services. The need to maximize carbon sequestration, while simultaneously minimizing potential negative impacts on surrounding ecosystems (e.g., microbial degradation), was identified as a key challenge for sustainability-oriented farmers. Additionally, as arable land becomes increasingly scarce, many stakeholders agreed that there will be a need to carefully evaluate how land is allocated for the production of food and feed versus biofuel. The expansion of support and incentives available to small farmers who are able to use their land to produce a diversity of crops while also providing ecosystem services was noted as important.

Regarding the theme of expanded farmer access to diverse PBI and seed/crop varieties, it was widely agreed that context-specific (e.g., humidity, soil quality, field size, topography) farming may provide greater ecosystem services and support the development of more environmentally sustainable agricultural practices. While the coexistence of different farming systems and techniques (e.g., organic, agroecological, biotechnological) was identified as necessary for their freedom of choice, it was recognized that farmers have the responsibility to ensure their practices do not produce negative externalities (e.g., fertilizer run-off, pesticide contamination) that harm neighboring croplands. It was further noted that the ability of farmers to successfully design and implement their own production model is contingent upon having access to a diverse array of production technologies. The potential for PBI to be applied to diverse species beyond common commodity crops (i.e., maize, soy, wheat) was identified as a key opportunity for farmers worldwide to expand consumer choice, to create space in the marketplace for unique producer participation, and to promote nutritionally diverse diets. Further, it was posited that large multinationals may be well positioned to manage the production of commodity crops, while the larger population of small farmers could provide a wider range of specialty and non-commodity products (e.g., fruits, vegetables, ancient grains) to meet ranging consumer demands.

As international trade of agricultural products continues, and while global farmers use PBI technology to varying degrees, it will become increasingly difficult to distinguish whether PBI technologies were involved in the production of individual agricultural products. As such, the ability of the E.U. to effectively enforce its existing regulatory policies on crop cultivation in Europe and globally was called into question. Specifically, the increased occurrence of contractual requirements to exclude and document the nonuse of PBI products or processes was noted as a reality faced by multinational agricultural organizations.

The need to adapt future iterations of the E.U. Common Agricultural Policy (CAP) in a manner that allows farmers to simultaneously profit from both the environmental services they provide (e.g., carbon sequestration, biodiversity preservation) and inherent product value was noted as a potential method to support and expand farmer participation in the global marketplace while improving agricultural sustainability. Moreover, it was argued that the CAP needs to be increasingly flexible to accommodate the existence and simultaneous implementation of diverse farming systems and PBI uses, to allow farmers the freedom to maximize their resources and contribute to reaching multiple social and personal goals. While it was hypothesized that future E.U. regulation will likely evolve to support the expanded use of PBI, it was expressed that additional support (e.g., incentives, supply chain communication) will be necessary to ensure that start-up breeders, farmers, and innovators have equal opportunities to participate in the marketplace. Given the reality that multinational suppliers have a greater ability to scale production and distribution, as well as to access nuanced market information, many indicated that information, education, and technological capacity-building campaigns to identify market trends, consumer demands, and opportunities for farmers will be critical for meeting market demands.

Limitations of the existing E.U. regulatory framework were identified as significant determinants of farmer and supplier choice in markets beyond the E.U. Because of the strength of European market demand for diverse food products and the reality that many food, feed, and agricultural products derived worldwide are routed through and processed within E.U. countries, it was noted that choices by European consumers overshadow the preferences of farmers in more resource-scarce or highly trade-dependent regions. By expanding opportunities to participate in global market decisions, it was noted that non-European farmers can exert more influence on agricultural issues based on the particularities of their geographical and societal priorities. Broadscale sharing of agricultural resources across the global network of food sector stakeholders was further identified as an opportunity for information and data sharing among farmers that could benchmark growing conditions (e.g., climate and weather patterns), yield, and soil quality. Though intellectual property rights were mentioned as necessary to acknowledge the originators of PBI, it was widely recognized that providing more open access to researchers, suppliers, and farmers will be critical to creating a more diverse array of market choices for high quality food products. The continuing emergence of PBI is widely viewed as essential to supporting sustainable agriculture.

Acknowledgment

Numerous individuals and organizations have made important contributions to the Institute on Science for Global Policy (ISGP) as it organized, facilitated, convened, and moderated the Sustainable Agriculture: The Role of Plant Breeding Innovation (SA-PBI) conference with support from the American Seed Trade Association, Euroseeds, and U.S. Soybean Export Council. Special attention was given to the presentation of views and priorities concerning the future of sustainable agriculture as it relates to the use of plant breeding innovations throughout global and domestic agricultural systems, with a focus on European and U.S. priorities. In recognition of the health and travel constraints imposed by the global COVID-19 pandemic, the ISGP SA-PBI conference was convened on November 17 and 18, 2020, using a virtual (Internet) format. The entire ISGP SA-PBI conference was conducted under the Chatham House Rule (not-for-attribution).

As detailed in the agenda provided herein, the format spanned two days and involved written material including four, three-page position papers and one introductory paper prepared by invited subject-matter experts. Debates of the position papers were moderated by ISGP staff, as were the plenary caucuses that focused on identifying Areas of Consensus (AOCs) and Actionable Next Steps (ANSs).

The ISGP greatly appreciates the willingness of all those in the scientific, governmental, public advocacy, and private sector communities who agreed to be interviewed (approximately 170 in total) by the ISGP staff in their efforts to organize the content of this ISGP SA-PBI conference. Of special significance were the contributions of those invited subject-matter experts who agreed to prepare position and introductory papers.

The effectiveness of every ISGP conference critically depends on the active engagement of all invited participants in the often-intense debates and probing caucuses. The exchange of strongly held views, innovative proposals, and critiques generated throughout the debates and caucuses foster an unusual, and perhaps unique, environment providing a credible understanding of fundamental issues for both the specialist and non-specialist. The ISGP debate/caucus format informs public and private sector policies spanning regulatory, public messaging, non-governmental organizational positions, and business decisions. The ISGP is greatly indebted to all those who participated in the not-for-attribution (Chatham House

Rule) debates and plenary caucuses. The ISGP is greatly indebted to all those who participated in the ISGP SA-PBI conference.

The members of the ISGP Board of Directors also deserve recognition for their time and efforts in helping to create a viable, increasingly relevant, not-for-profit organization focused on addressing many of the most important scientific, technological, and societal questions of our time.

The energetic, highly professional interviewing, organizational, facilitation, moderation, and writing skills of the ISGP staff were essential to creatively structuring the ISGP SA-PBI conference. These same skills and commitments were evident in accurately capturing the often-diverse views and perspectives expressed in the critical debates and caucuses as well as in the written material presented here. The biographies of position paper authors, ISGP staff, and ISGP Board of Directors are all provided in the Appendix of this book.

Dr. George H. Atkinson
Founder and Executive Director
Institute on Science for Global Policy

Informal Glossary of Relevant Terms

Base Editing — "The conversion of one target base into another (e.g. A:T, G:C, C:G, or T:A). Base editing is achieved with the help of DNA and RNA base editors that allow the introduction of point mutations at specific sites, in either DNA or RNA" (Basturea, 2020).

Biodynamic Farming — A systematic, ecologically, and ethically focused approach to farming, gardening, food, and nutrition. "Biodynamics is rooted in the work of philosopher and scientist Dr. Rudolf Steiner, whose 1924 lectures to farmers [proposed] a new way to integrate scientific understanding with a recognition of spirit in nature" (Steiner, 1993).

Biotechnology — "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use" (FAO, 2011).

Cartagena Protocol — "An international treaty agreement which aims to ensure the safe handling, transport, and use of living modified organisms resulting from modern biotechnology that may have adverse effects on biological diversity, taking also into account risks to human health" (Convention on Biological Diversity, 2020).

Coexistence — "Coexistence refers to the concurrent cultivation of conventional, organic, intellectual property, and genetically engineered (GE) crops consistent with underlying consumer preferences and farmer choices" (USDA, 2020).

Conventional Farming — "Conventional farming is the use of seeds that have been genetically altered using a variety of traditional breeding methods, excluding biotechnology, and are not certified as organic" (USDA, 2015).

Conventional Plant Breeding — "The development or improvement of cultivars using conservative tools for manipulating a plant genome within the natural genetic boundaries of the species. The general strategy is to breed a [variety] whose genetic purity and productivity can be sustained by its natural mating system" (Acquaah, 2015).

Court of Justice of the European Union (CJEU) — The CJEU interprets E.U. law to ensure it is applied in the same way in all E.U. countries, and settles all disputes between national governments and E.U. institutions. The CJEU interprets and enforces the law, annuls E.U. legal acts, ensures the E.U. takes action, and sanctions E.U. institutions (European Union, 2020).

European Commission — The politically independent executive arm of the European Union (E.U.). The Commission is responsible for proposing new laws, managing E.U. policies, allocating funding, enforcing E.U. law, and representing the E.U. internationally. It consists of 27 leaders, one from each member country of the E.U. (European Union, 2020).

Gene Editing — Technologies that cut DNA at specific points and allow removal, addition, or replacement of DNA at the point of incision. "Genome editing technologies allow scientists to change DNA, leading to changes [in traits]" (National Human Genome Research Institute, 2019). CRISPR and Transcription Activator-like Effector Nucleases (TALENS) are examples of gene editing technologies.

Genetically Modified Organism (GMO)* —
In the European Union (E.U.)
According to the Directive 2001/18/EC of the E.U. Parliament and of the Council of 12 March, 2001 on the deliberate release into the environment of GMO and repealing Council Directive 90/220/EEC:

> "'GMO' means an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination" (EUR-Lex, 2001).

In the United States (U.S.)
The U.S. government does not have a legal definition for a GMO. However, the U.S. Department of Agriculture (USDA) generally refers to a GMO as, "an organism produced through genetic modification." The USDA defines genetic modification as:

> "The production of heritable improvements in plants or animals for specific uses, via either genetic engineering or other more traditional methods. Some countries other than the U.S. use this term to refer specifically to genetic engineering" (USDA, 2020).

**Due to the varying definitions of GMO recognized by different entities, context is often important to understand the use of the term. In the context of the Institute on Science for Global Policy (ISGP) Sustainable Agriculture: The Role of Plant Breeding Innovation (SA-PBI) conference, participants generally used the term GMO to encompass transgenic organisms, at a minimum.*

Heterosis (Hybrid vigor) — "Heterosis describes the phenomenon in which hybrids formed between individuals of the same or closely related species are more robust or vigorous than their parents. Thus, the terms heterosis and hybrid vigor are often used interchangeably" (Timberlake, 2013).

Living Modified Organism (LMO) — "Any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology" (Convention on Biological Diversity, 2013).

Marker Assisted Breeding (MAB) — "Marker-assisted Breeding (MAB) is a novel technique of indirect selection of traits in [plants] in breeding. Marker here refers to all kinds of DNA markers, usually visualized by the polymorphisms of a DNA sequence" (ScienceDirect, 2004).

Organic Agriculture — "A concept and practice of agricultural production that focuses on production without the use of synthetic inputs and does not allow the use of GMO" (USDA, 2020).

Organic Heterogeneous Material — Plant reproductive material, "characteri[z]ed by [a] high level of phenotypic and genetic diversity, and [a] dynamic nature to evolve and adapt to certain growing conditions. In contrast to [(i)] seed mixtures that are rebuilt annually based on varieties, or synthetic varieties derived by intercrossing of a defined set of parental materials which are repeatedly cross-pollinated to reconstruct a stable population, or [(ii)] conservation and amateur varieties including landraces, organic heterogeneous material is intended to adapt to various biotic and abiotic stresses due to repeated natural and human selection and therefore is expected to change over time" (European Commission, 2020).

Participatory Plant Breeding (PPB) — PPB is an approach to breeding that involves farmers, researchers, and breeders to adapt crop and seed varieties to specific regional characteristics and farming practices. PPB often involves extension initiatives to evaluate the long-term effects of various breeding strategies and techniques (Shelton et al., 2016).

Plant Breeding Innovation (PBI) — PBI, in the context of the SA-PBI conference, refers to the broad range of recent, new, and emerging technologies, strategies, and approaches used to improve various aspects of plant breeding processes (e.g., digital phenotyping, gene editing, gene mapping, MAB).

Precautionary Principle — "The precautionary principle enables decision-makers to adopt precautionary measures when scientific evidence about an environmental or human health hazard is uncertain and the stakes are high" (Bourguignon, 2015).

RNA Interference (RNAi) — "RNA interference (RNAi) or Post-Transcriptional Gene Silencing (PTGS) is a conserved biological response to double-stranded RNA that mediates resistance to both endogenous parasitic and exogenous pathogenic nucleic acids, and regulates the expression of protein-coding genes" (National Center for Biotechnology Information, 2020).

Transgenic Organism — "An organism resulting from the insertion of genetic material from another organism using recombinant DNA techniques" (Haynes, 2008).

Variety — "A subdivision of a species for taxonomic classification also referred to as a 'cultivar.' A variety is a group of individual plants that is uniform, stable, and distinct genetically from other groups of individuals in the same species" (USDA, 2020).

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Biographical Information of Presenters

Carl Jones, Ph.D., Plant Sciences Director, Mars Advanced Research Institute (MARI), London, UK

As the Mars Advanced Research Institute's (MARI) Plant Sciences Director, Dr. Carl Jones is responsible for developing science and technology to support ecological and economically sustainable agriculture. Carl was an early pioneer in the Organic Seed industry and a founder of the Corvallis Farmers Market and the Organic Seed Alliance. Dr. Jones received his Ph.D. in genetics from University of California, Davis, where he studied nutritional improvement of tomatoes. His work with Seeds of Change resulted in many new flower and vegetable varieties. Carl was Head of Innovation and New Technologies and served on the global research leadership team at Bayer/Monsanto Vegetables for 15 years. Carl is author of numerous papers and inventor on more than a dozen US and international patents. He currently serves as Co-Chair of the USDA Capsicum (peppers) Crop Germplasm Committee, and the advisory board of the Oregon State University Leadership Academy.

Mars Advanced Research Institute (MARI)

The Mars Advanced Research Institute (MARI) provides Mars with capabilities and connectivity to be on the cutting edge of science and technology. Their mission is to drive long-term breakthroughs that unlock crucial innovation by leveraging a global network of external academic, research, and scientific partners, to link external expertise and innovation with business.

Jannes Maes, President, European Council of Young Farmers (CEJA), Flanders, Belgium

Jannes Maes, a dairy farmer from Flanders in northern Belgium, has been passionate about farming and horticulture since childhood. He holds a degree in agriculture from Thomas More University of Applied Sciences in Flanders and is currently President of the European Council of Young Farmers (CEJA). As a CEJA Vice President, he was an international representative for Groene Kring, the Flemish young farmers' organization. When not engaged in politics and representation, Maes can be found working alongside his father and brother on their family farm.

European Council of Young Farmers (CEJA)

CEJA acts as a forum for communication between young farmers and European decision-makers. Its main objective is to promote a younger and more innovative agricultural sector across the EU-27 and to create good working and living conditions for young people setting up in farming and those who are already "young farmers".

Monika Messmer, Ph.D., Group Lead of Plant Breeding, Department of Crop Sciences, Research Institute of Organic Agriculture, FiBL, Frick, Baselland, Switzerland

Dr. Monika Messmer has led the plant breeding team at the FiBL, Switzerland since 2009. The main focus of her research is breeding for mixed cropping systems and for plant microbe interaction. She is also president of the European Consortium for Organic Plant Breeding, board member of Bioverita, and a member of the IFOAM Seed Platform and EUCARPIA section of organic and low input agriculture. She is engaged in several national and European projects, and is the scientific coordinator of the EU project LIVESEED. She initiated the participatory organic cotton breeding projects Green Cotton and Seeding the Green Future in India. She recieved her Ph.D. in plant breeding from University of Hohenheim, Germany.

Research Institute of Organic Agriculture, FiBL

FiBL is an independent, non-profit, research institute with the aim of advancing cutting-edge science in the field of organic agriculture, by promoting research and projects that help farmers improve their productivity with consideration of environmental and health impacts.

Dr. Matin Qaim, Ph.D., Professor, University of Göttingen, Germany

Dr. Matin Qaim is Professor of International Food Economics and Rural Development at the University of Goettingen, Germany. He previously held research and teaching positions at the Universities of Hohenheim, Bonn, Kiel, and California at Berkeley. He holds a doctoral degree in agricultural economics from the University of Bonn. His main research areas include the economics of food security, sustainable food systems, and smallholder agriculture. He has research and project experience in Europe, the USA, and numerous countries of Africa, Asia, and Latin America. He is a member of the German National Academy of Sciences (Leopoldina) and was recently recognized as Fellow of the American Agricultural and Applied Economics Association (AAEA). He has served on different high-level expert committees, including for the Global Panel on Agriculture and Food Systems for Nutrition, the International Maize and Wheat Improvement Center (CIMMYT), and the German Government and Parliament.

University of Göttingen

The University of Göttingen, founded in 1737, is a research university committed to the values of social responsibility of science, democracy, tolerance, and justice.

René Smulders, Ph.D., Business Unit Manager, Plant Breeding, Wageningen University & Research (WUR), Netherlands

Dr. René Smulders is the Business Unit Manager for Plant Breeding at Wageningen University & Research. His research focuses on the opportunities of new plant breeding techniques, on developing tools for genetic mapping in polyploid crops, including rose, and on how to make wheat varieties that are safe for people with coeliac disease. Previously, he was the Research Group Lead in Identity and Genetic Diversity at WUR. He received his M.Sc. in Biology from Radboud University Nijmegen, the Netherlands.

Wageningen University & Research (WUR)

Wageningen University & Research is a collaboration between Wageningen University and the Wageningen Research foundation in the Netherlands. WUR combines natural and social science research to investigate three core areas: (i) food, feed, and biomass production (ii) natural resources and the living environment (iii) society and well being.

Biographical Information of ISGP Board of Directors

Dr. George Atkinson, Chairman

Dr. Atkinson founded the Institute on Science for Global Policy (ISGP) and is an Emeritus Professor of Chemistry, Biochemistry, and Optical Science at the University of Arizona. He is former head of the Department of Chemistry at the University of Arizona, the founder of a laser sensor company serving the semiconductor industry, and Science and Technology Adviser (STAS) to U.S. Secretaries of State Colin Powell and Condoleezza Rice. He launched the ISGP in 2008 as a new type of international forum in which credible experts provide governmental and societal leaders with understanding of the science and technology that can be reasonably anticipated to help shape the increasingly global societies of the 21st century. Dr. Atkinson has received National Science Foundation and National Institutes of Health graduate fellowships, a National Academy of Sciences Post Doctoral Fellowship, a Senior Fulbright Award, the SERC Award (U.K.), the Senior Alexander von Humboldt Award (Germany), a Lady Davis Professorship (Israel), the first American Institute of Physics' Scientist Diplomat Award, a Titular Director of the International Union of Pure and Applied Chemistry, the Distinguished Service Award (Indiana University), an Honorary Doctorate (Eckerd College), the Distinguished Achievement Award (University of California, Irvine), and was selected by students as the Outstanding Teacher at the University of Arizona. He received his B.S. (high honors, Phi Beta Kappa) from Eckerd College and his Ph.D. in physical chemistry from Indiana University. He was recently the President of Sigma Xi, The Scientific Research Society. His educational scientific research and diplomatic achievements have been recognized with distinguished appointments and awards in 16 countries.

Dr. Janet Bingham, Member

Dr. Bingham is former President of the George Mason University (GMU) Foundation and Vice President of Advancement and Alumni Relations. GMU is the largest research university in Virginia. Previously, she was President and CEO of the Huntsman Cancer Foundation (HCF) in Salt Lake City, Utah. The foundation is a charitable organization that provides financial support to the Huntsman Cancer Institute, the only cancer specialty research center and hospital in the Intermountain West. Dr. Bingham also managed Huntsman Cancer Biotechnology Inc. In addition, she served as Executive Vice President and Chief Operating Officer with the Huntsman Foundation, the private charitable foundation established by

Jon M. Huntsman Sr. to support education, cancer interests, programs for abused women and children, and programs for the homeless. Before joining the Huntsman philanthropic organizations, Dr. Bingham was the Vice President for External Relations and Advancement at the University of Arizona. Prior to her seven years in that capacity, she served as Assistant Vice President for Health Sciences at the University of Arizona Health Sciences Center. Dr. Bingham was recognized as one of the Ten Most Powerful Women in Arizona.

Dr. Mike Buch, Member

Dr. Buch holds B.A., M.S., and Ph.D. degrees in Analytical Chemistry and Biotechnology. He has nearly 3 decades of experience in the consumer healthcare industry in various roles of increasing responsibility with some of the world's leading companies. He has broad-based knowledge of consumer healthcare and currently serves as Chief Science Officer and Board Member at Young Living Essential Oils, a rapidly growing multibillion-dollar international wellness company and the largest provider of essential oils in the world. He is directly responsible for leading Research, Development, Product Management, and Quality Assurance across Young Living. Dr. Buch has expertise in leading global strategic development programs, open innovation programs, licensing programs, consumer healthcare R&D, advanced technologies labs, advanced optical analysis labs, and biosensor design and research. His work has directly led to the development of consumer healthcare products with annual sales exceeding $3 billion and his products have been marketed in more than 100 countries. His success has resulted in more than a dozen patents in the healthcare field, several books, and numerous articles published in peer-reviewed journals. He is also a member of several prestigious associations, including the American Chemical Society, The New York Academy of Science, and the American Association for the Advancement of Science.

Mr. Fred Downey, Member

Mr. Downey is a former U.S. Army strategist and longtime defense and international affairs expert on Capitol Hill and was vice president of national security at Aerospace Industries Association (AIA). Downey joined AIA from the office of Connecticut Senator Joe Lieberman where he served as Senior Counselor and Legislative Aide for Defense and Foreign Affairs. He had been the senator's key staff person on these issues for 12 years. As Lieberman's representative to the Senate Armed Services Committee, Downey staffed the senator in his role as chairman of the Airland Subcommittee, overseeing Army and Air Force policy and budget issues and the annual defense authorization bill. Before joining Lieberman, Downey worked on defense analytical services for TASC. That came after a 24-year career in the U.S.

Army, including Pentagon postings as Assistant to the Director of Net Assessments at OSD and Strategy Team Chief for the Strategic Plans and Policy Directorate on the Department of the Army Staff.

Dr. Linda Duffy, Member

Dr. Duffy recently retired as a U.S. Federal Government Senior Scientist Administrator in the Department of Health Human Services, National Institutes of Health, at the National Center for Complementary and Integrative Health, where she currently serves as a post-retirement Special Volunteer to the Director. Among her many service achievements at the NIH, she launched and chaired the Trans-NIH Probiotics/ Prebiotics and Microbiome Inter-agency Work Group and served for many years as an Inter-agency Subject Matter Expert in ad hoc advisory capacities as committee member and Chair. Dr. Duffy received a DHHS Innovation Award in 2016 and was appointed to serve in the dual role of Senior Scientific Advisor in the DHHS Office of the Secretary, within the Office of the National Coordinator, Division of Science Technology. Prior to her distinguished federal government career, she was a former Peace Corps Volunteer in Cote d'Ivoire, West Africa and subsequently served in a dual capacity as Scientific Director of the Women and Children's Health Research Foundation and as a Distinguished Professor Emeritus with former joint appointments in the Departments of Pediatrics, Epidemiology, and Microbial Pathogenesis at the University of Buffalo. She received her Master's degree from Dartmouth College and completed her doctoral and postdoctoral studies under NIH National Cancer Institute Research Fellowships at the University of Buffalo

Dr. Tom Fingar, Member

Dr. Fingar is a Shorenstein APARC Fellow in the Freeman Spogli Institute for International Studies at Stanford University. He was the inaugural Oksenberg-Rohlen Distinguished Fellow in 2010-2015 and the Payne Distinguished Lecturer at Stanford in 2009. From 2005 through 2008, he served as the first Deputy Director of National Intelligence for Analysis and, concurrently, as Chairman of the National Intelligence Council. Dr. Fingar served previously as Assistant Secretary of the State Department's Bureau of Intelligence and Research (2000-2001 and 2004-2005), Principal Deputy Assistant Secretary (2001-2003), Deputy Assistant Secretary for Analysis (1994-2000), Director of the Office of Analysis for East Asia and the Pacific (1989-1994), and Chief of the China Division (1986-1989). Between 1975 and 1986 he held a number of positions at Stanford University, including Senior Research Associate in the Center for International Security and Arms Control. Dr. Fingar is a graduate of Cornell University (A.B. in Government and History, 1968), and Stanford University (M.A., 1969 and Ph.D., 1977 both in Political Science). His most recent books are *Reducing Uncertainty: Intelligence Analysis and National Security*(Stanford, 2011), *The New Great Game: China and South and Central Asia in the Era of Reform*, editor (Stanford, 2016), *Uneasy Partnerships: China and Japan, the Koreas, and Russia in the Era of Reform,* editor(Stanford, 2017), and *Fateful Decisions: Choices that Will Shape China's Future*,edited with Jean C. Oi (Stanford, 2020).

Mr. Jim Kolbe, Member

For 22 years, Mr. Kolbe served in the United States House of Representatives, elected in Arizona for 11 consecutive terms, from 1985 to 2007. Mr. Kolbe is currently serving as a Senior Transatlantic Fellow at the German Marshall Fund of the United States, and as a Senior Adviser to McLarty Associates, a strategic consulting firm. He advises on trade matters as well as issues of effectiveness of U.S. assistance to foreign countries, on U.S.-European Union relationships, and on migration and its relationship to development. He is also Co-Chair of the Transatlantic Taskforce on Development with Gunilla Carlsson, the Swedish Minister for International Development Cooperation. He also is an adjunct Professor in the College of Business at the University of Arizona. While in Congress, he served for 20 years on the Appropriations Committee of the House of Representatives, was chairman of the Treasury, Post Office and Related Agencies subcommittee for four years, and for his final six years in Congress, he chaired the Foreign Operations, Export Financing and Related Agencies subcommittee. He graduated from Northwestern University with a B.A. degree in Political Science and then from Stanford University with an M.B.A. and a concentration in economics.

Dr. David Moran, Member

Dr. Moran is President of Technology International Partnerships, LLC, and Past-Publisher of Sigma Xi, The Scientific Research Society, "American Scientist" and the "Chronicle of the New Researcher." He has served as President of the National Technology Transfer Center; Director of Industrial Advanced Development & Industrial Outreach, Advanced Technology, Office of Naval Research; Program Element Administrator for Nuclear Propulsion, R&D, Naval Material Command; Director, David Taylor Institute; Assistant Technical Director, Director of Research, and Technology Director, Naval Ship R&D Center. His professional experience in research and teaching at universities includes the U.S. Naval Academy, Full Professor, Navy Chair; West Virginia University; George Washington University; Research Naval Architect, US Navy. He earned a Ph.D. in Hydrodynamics & Mathematics, IIHR; Sc.M., M.I.T, Ocean Engineering, Hydrodynamics; Sc.B., M.I.T.; Harvard University; University Iowa; and Graduate, Federal Executive Institute. He served at Harvard University's JFK School as Senior Official for National Security. He is a member of the Boards of: Tucker Community Foundation; Community Trust Foundation; Preston Community Fund; and Past-Treasurer, Board of Directors, Maryland Garrett College. His publications include 102 Scientific Papers, 12 Patents in Hydrodynamics and Aerodynamics, and two published Books.

Mr. Joseph Nimmich, Member

Mr. Nimmich is a Partner at Potomac Ridge Consulting. He formerly was Senior Executive Advisor at Booz Allen Hamilton's Civil and Commercial Group. Prior to Booz Allen Hamilton, he served as the Deputy Administrator of the Federal Emergency Management Agency (FEMA) from September of 2014 until January 2017. During his tenure, his primary focus was on strengthening and institutionalizing FEMA's business architecture over the long term to achieve the Agency's mission. He joined FEMA in 2013, as the Associate Administrator for the Office of Response and Recovery. He was responsible for directing the Response, Recovery, and Logistics Directorates, as well as the Office of Federal Disaster Coordination. Prior to joining FEMA, he was the Director of Maritime Surveillance and Security at Raytheon Corp., where he directed maritime surveillance and security operations, as well as their emergency response capabilities. He served in the U.S. Coast Guard for more than 33 years, retiring as a Rear Admiral. His Coast Guard assignments included the First Coast Guard District based in Boston, Massachusetts, where he was responsible for all Coast Guard operations across eight states in the northeast and 2,000 miles of coastline from the U.S.-Canadian border to northern New Jersey. He earned his M.B.A. from the Stern School of Business at New York University.

Dr. Charles Parmenter, Member

Dr. Parmenter is a Distinguished Professor Emeritus of Chemistry at Indiana University. He also served as Professor and Assistant and Associate Professor at Indiana University in a career there that spanned nearly half a century (1964-2010). He earned his bachelor's degree from the University of Pennsylvania and served as a Lieutenant in the U.S. Air Force from 1955-57. He worked at DuPont after serving in the military and received his Ph.D. from the University of Rochester and was a Postdoctoral Fellow at Harvard University. He has been elected a Member of the National Academy of Sciences and the American Academy of Arts and Sciences, and a Fellow of the American Physical Society and the American Association for the Advancement of Science. He was a Guggenheim Fellow, a Fulbright Senior Scholar, and received the Senior Alexander von Humboldt Award in 1984. He has received the Earle K. Plyler Prize, was a Spiers Medalist and Lecturer at the Faraday Society, and served as Chair of the Division of Physical Chemistry of the American Chemical Society, Co-Chair of the First Gordon Conference on Molecular Energy

Transfer, Co-organizer of the Telluride Workshop on Large Amplitude Motion and Molecular Dynamics, and Councilor of Division of Chemical Physics, American Physical Society.

Mr. Thomas Pickering, Member

Mr. Pickering is Vice Chairman of Hills & Co, international consultants. He co-chaired a State-Department- sponsored panel investigating the September 2012 attack on the U.S. diplomatic mission in Benghazi. He served as U.S. ambassador to the United Nations in New York, the Russian Federation, India, Israel, El Salvador, Nigeria, and the Hashemite Kingdom of Jordan. Mr. Pickering also served on assignments in Zanzibar and Dar es Salaam, Tanzania. He was U.S. Under Secretary of State for Political Affairs, president of the Eurasia Foundation, Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs, and Boeing Senior Vice President for International Relations. He also co-chaired an international task force on Afghanistan, organized by the Century Foundation. He received the Distinguished Presidential Award in 1983 and again in 1986 and was awarded the Department of State's highest award, the Distinguished Service Award in 1996. He holds the personal rank of Career Ambassador, the highest in the U.S. Foreign Service. He graduated from Bowdoin College and received a master's degree from the Fletcher School of Law and Diplomacy at Tufts Universitya second master's degree from the University of Melbourne in Australia.

Dr. Eugene Sander, Member

Dr. Sander served as the 20th president of the University of Arizona (UA), stepping down in 2012. He formerly was vice provost and dean of the UA's College of Agriculture and Life Sciences, overseeing 11 academic departments and two schools, with research stations and offices throughout Arizona. He also served as UA Executive Vice President and Provost, Vice President for University Outreach and Director of the Agricultural Experiment Station and Acting Director of Cooperative Extension Service. Prior to his move to Arizona, Dr. Sander served as the Deputy Chancellor for biotechnology development, Director of the Institute of Biosciences and Technology, and head of the Department of Biochemistry and Biophysics for the Texas A&M University system. He was Chairman of the Department of Biochemistry at West Virginia University Medical Center and Associate Chairman of the Department of Biochemistry and Molecular Biology at the College of Medicine, University of Florida. As an officer in the United States Air Force, he was the assistant chief of the biospecialties section at the Aerospace Medical Research Laboratory. He graduated with a bachelor's degree from the University of Minnesota, received his master's degree and Ph.D. from Cornell University and completed postdoctoral study at Brandeis University. As a biochemist, Dr. Sander worked in the field of mechanisms by which enzymes catalyze reactions.

Dr. Ben Tuchi, Member and Secretary/Treasurer

Dr. Tuchi serves on the boards of two additional non-profit corporations; he is Treasurer of the Campus Research Corporation and President of the Arizona Research Park Authority. He received his B.S. and M.S. degrees in Business Administration from the Pennsylvania State University and his Ph.D. in Finance from St Louis University. His full time teaching career began in 1961 at St. Francis College and continued until 1976 at West Virginia University. From 1976 through 1996 he served in cabinet levels at West Virginia University, The University of Arizona, The University of North Carolina at Chapel Hill, and finally as Senior Vice Chancellor for Business and Finance of the University of Pittsburgh. During those assignments he was simultaneously a tenured professor of finance. He retired from the last executive post in 1996 and returned to a full- time teaching position as Professor of Finance at the University of Pittsburgh, until his retirement in 1999. For the two years prior to his retirement he was the Director of Graduate Programs in Business in Central Europe, at Comenius University, making his home in Bratislava, The Slovak Republic.

Mr. Richard Armitage, Special Adviser

Mr. Armitage is the President at Armitage International, where he assists companies in developing strategic business opportunities. He served as Deputy Secretary of State from March 2001 to February 2005. Mr. Armitage, with the personal rank of Ambassador, directed U.S. assistance to the new independent states (NIS) of the former Soviet Union. He filled key diplomatic positions as Presidential Special Negotiator for the Philippines Military Bases Agreement and Special Mediator for Water in the Middle East. President Bush sent him as a Special Emissary to Jordan's King Hussein during the 1991 Gulf War. Mr. Armitage also was Deputy Assistant Secretary of Defense for East Asia and Pacific Affairs in the Office of the Secretary of Defense. He graduated from the U.S. Naval Academy. He has received numerous U.S. military decorations as well as decorations from the governments of Thailand, Republic of Korea, Bahrain, and Pakistan. Most recently, he was appointed an Honorary Companion of The New Zealand Order of Merit. He serves on the Board of Directors of ConocoPhillips, ManTech International Corporation, and Transcu Ltd., is a member of The American Academy of Diplomacy as well as a member of the Board of Trustees of the Center for Strategic and International Studies.

Jennifer Boice, Special Assistant to the Board

Ms. Boice worked for 25 years in the newspaper industry, primarily at the Tucson Citizen and briefly at USA Today. She was the Editor of the Tucson Citizen when it was closed in 2009. Additional appointments at the Tucson Citizen included Business News Editor, Editor of the Online Department, and Senior Editor. She also was a business columnist. She received her M.B.A. from the University of Arizona and graduated from Pomona College in California with a degree in Economics.

Biographical information of ISGP Leadership and Staff

Dr. George H. Atkinson, Founder and Executive Director

The professional career of Dr. Atkinson spans several diverse arenas including academic responsibilities for teaching, scientific research, grant preparation, and administration within university communities, duties as the Founder and Chief Executive Officer of Innovative Laser Corp. that designed high sensitivity laser sensors for the semiconductor industry, and public service as a science and technology adviser within the U.S. government. His U.S. government activities crossed different agencies and departments and included service as the Science and Technology Adviser to the Secretaries of State Colin Powell and Condoleezza Rice. His recent efforts, facilitating the use of credible scientific understanding in the formulation and implementation of governmental, private sector, and societal policies worldwide, are reflected in his launching of the Institute on Science for Global Policy (ISGP). Dr. Atkinson is an Emeritus Professor of Chemistry, Biochemistry, and Optical Sciences at the University of Arizona. He has been recognized for his teaching (Outstanding Teacher at the University of Arizona; Distinguished Alumni Award, Indiana University; Honorary Doctorate and MacArthur Award, Eckerd College) and research (Senior Alexander Humboldt Award and Senior Fulbright Fellow, Germany; Senior SERC Awards at the Royal Institution of Great Britain and Oxford University, U.K; Lady Davis Professorships at Hebrew University and the Technion, Israel; Distinguished Visiting Professor, University of Tokyo, Japan; Distinguished Professor Award, University of California, Irvine). He was elected in 2014 President of the Sigma XI, The Scientific Research Society.

Ms. Kat Wheeler, Program Director

In her position as Program Director for the ISGP, Ms. Wheeler plays an integral leadership role in the conceptualization, design, organization, and implementation of ISGP programs. Ms. Wheeler initiated her work at the ISGP in 2019 as Associate Program Director for the FDA sponsored ISGP Innovative Foods and Ingredients Conference (2019) which engaged 70+ senior leaders from the private sector, public advocacy, governmental, and scientific and technological communities. Subsequently, Ms. Wheeler has engaged in topics spanning food traceability, climate impacts on agriculture, plant breeding, agricultural sustainability, communication and food labeling, medical supply chain security, and veterinary medical countermeasures, etc. Prior to her time at the ISGP, Ms. Wheeler carried out work in support of farm-to-school in Michigan, conducted research on coffee farmers' views on third party certifications in Costa Rica, and volunteered for farmworker rights in Florida. Ms. Wheeler received a B.A. in Environmental Studies with a minor in Biology from Eckerd College, in St. Petersburg, FL.

Ms. NiCole Bice, Program Coordinator

Ms. Bice has a diverse background in both education and business experience. Before joining the ISGP, she was an Academic Coordinator at a Professional Sports Academy and has served as an Administrator, Lab Facilitator, Teacher, and Curriculum Supervisor at a variety of schools and organizations. She attended the University of Arizona in Tucson and graduated with a B.A. degree. She has a lifelong interest in education, business, and current science-related topics. She recently received certifications in both global education perspectives and business management.

Ms. Jennifer Boice, Financial Director

Ms. Boice worked for 25 years in the newspaper industry, primarily at the Tucson Citizen and briefly at USA Today. She was the Editor of the Tucson Citizen when it was closed in 2009. Additional appointments at the Tucson Citizen included Business News Editor, Editor of the Online Department, and Senior Editor. She also was a business columnist. She received her M.B.A. from the University of Arizona and graduated from Pomona College in California with a degree in economics. She has worked with the Institute on Science for Global Policy since 2010 in a variety of positions.

Ms. Daniela Baeza Breinbauer, Senior Fellow

Ms. Baeza Breinbauer is a Project Officer and Researcher at LSE Consulting where she oversees all projects in the fields of Environment; Development Economics; Health; and Behavioural Science. By training she is a Development and Environmental Economist with a background in Human Rights and Science Policy. She has previously consulted for a variety of government and non-government institutions including the United Nations, European Commission, EU Committee of the Regions, U.S. Government, and the Government of India. She holds an M.Sc. in International Development Management (Applied Development Economics Specialism) from the London School of Economics, and a double B.A. in Global Affairs/International Relations and Political Science, with a focus on Human Rights Law, from Eckerd College. She is a current post-graduate candidate on the Environmental Economics and Climate Change (EECC) program at the LSE.

Mr. Ciaran Fitzpatrick, Senior Fellow

Mr. Fitzpatrick graduated with Honors from Eckerd College, where he received a B.S. in Biology, as well as a second major in International Relations & Global Affairs. As an ISGP Fellow, he has played a key supportive role in the development and organization of current and prospective ISGP programs. Notably, he played an integral role in the planning and execution of the Future of Modern Agriculture Conference, which was convened with support from the U.S. Department of State and engaged approximately 36 senior stakeholders, including diplomats, UN representatives, private sector leaders, civil society groups, and scientific/academic experts. At Eckerd, Mr. Fitzpatrick was a Ford Apprentice Scholar as well as a cell biology research assistant. He hopes to become a biological researcher, using scientific communication to bridge the gap between research and policy. He takes special interest in the fields of food security and sustainability, global health, climate change, ecology, biodiversity, and genomics.

Ms. Margaret Patkus, Senior Fellow

Ms. Patkus majored in Environmental Studies and Race & Ethnic Studies at St. Olaf College (Northfield, MN). Her passions for food justice, community health, and sustainability were ignited during her internship as an educator with the Poughkeepsie Farm Project (Poughkeepsie, NY) during the summer of 2016. This led her to pursue several community engagement roles with non-profit organizations as well as a semester in Italy studying the economics and culture of sustainable food systems. Since joining the ISGP as a Fellow in September of 2019, Ms. Patkus has played a key supportive role in the development and organization of current and prospective ISGP programs, contributing to internal research efforts, stakeholder identification and engagement, and other critical planning and analysis. This work has spanned topics such as global bioeconomy development, agricultural biotechnology, agroecology/soil health, climate change impacts on the nutritional quality of food, food traceability, and plant breeding.

Mr. Christopher Samuel, Senior Fellow

Chris Samuel has 20+ years of global communications and public affairs expertise in the food-agriculture (Bayer, Monsanto), consumer goods (P&G, J&J), industrial (Siemens) and non-profit sectors in highly regulated and multicultural environments. As Director of Corporate Preparedness and Engagement at Bayer, he led external affairs strategy on corporate reputation, biotechnology and data science technologies on sustainability, transparency, safety, human rights, and trade issues. He has also led 15+ sustainability partnerships with Governments and NGOs incl. Conservation International, UNICEF, Habitat for Humanity, Room to Read and others. Chris served as the Chair - CropLife's Communications Committee, Co-Chair - U.S.-ASEAN Business Council Food & Agriculture Committee, and represented Bayer at BIO, Consumer Brands Association, CRISPRcon, World Economic Forum, and World Business Council for Sustainable Development. He was a Professor of Corporate Affairs at the Singapore Management University, and Xavier Institute of Communications. Chris is Board Member at STAGES St. Louis, and Thespo youth theatre festival.

Mr. Brian Akpan, Adjunct Fellow

Mr. Akpan is a graduate of the University of Arizona in the field of Materials Science and Engineering. During his time in college, he was heavily influenced by an interest in sustainable and environmentally sound materials. He is deeply motivated to help the world operate efficiently by including a firm foundation of science, materials, and a pro-environmental, sustainable approach to creating new products. Mr. Akpan seeks to add value to the ISGP by bringing a strong reporting capability on research papers from the scientific to the public sphere.

Ms. Roxanne Hoorn, Adjunct Fellow

Ms. Hoorn's background is in science communication, research, ethics, and food systems. She is a graduate of Eckerd College, receiving two bachelor's degrees in Biology and Philosophy, respectively. She also served as Science Outreach Club President and Varsity Ethics Bowl Team Co-Captain while at Eckerd. Ms. Hoorn has worked as a lab teaching assistant in biology and genetics, STEM educator for Florida non-profits, farm hand and manager around North America, Food Systems Associate in Northern Michigan, and currently works as Genetics Teaching Assistant at Eckerd College in St. Petersburg, Florida. She seeks to communicate science to diverse audiences and find tangible, science-based solutions to environmental and humanitarian issues within our local and global food system.

Ms. Allison Rose, Adjunct Fellow

Ms. Rose is a current undergraduate at the University of California, Davis majoring in International Agriculture Development and minoring in Community Nutrition. Ms. Rose's interest in agriculture and nutrition spans her personal and professional life - alongside her studies, she interns at her school's student farm in the ecological garden, she is an avid cook and baker, and she loves to connect with others over food. Ms. Rose hopes to work in food and agriculture policy in the future, helping to spread sustainable and factual knowledge across the globe.

Ms. Arleigh Truesdale, Fellow

With a background in community engagement, urban agriculture, and advocacy, Ms. Truesdale is particularly interested in local food accessibility initiatives in city spaces. Since joining ISGP for its 2019 Innovative Foods and Ingredients, Ms. Truesdale contributed to the development of ISGP programming on traceability, biotechnology, and climate impacts on agriculture. She has held roles within the renewable energy and sustainable investment sector, promoting access to funding for grassroots, local infrastructure development. She is eager to continue engaging stakeholders across all sectors and to make policy development conversation accessible through upcoming ISGP programs. Ms. Truesdale received a B.A. in Sociology/Anthropology and Environmental Studies from St. Olaf College.

ISGP Programs and Conferences

Recent ISGP Conferences

Sustainable Agriculture: The Role of Plant Breeding Innovation conference, convened November 17-19, 2020, in an internet format, with support from the American Seed Trade Association and Euroseeds.

Science and Governance: The Future of Modern Agriculture conference, convened September 22, 2020, in a hybrid in-person (Rome, Italy) / internet format, with support from The Office of Agricultural Policy, U.S. Department of State.

Previous ISGP Conferences

All books from ISGP conferences are freely available to the public and can be downloaded from the ISGP site:
www.scienceforglobalpolicy.org.

Hardcopies of these books are available by contacting
nbice@scienceforglobalpolicy.org.

ISGP conferences and books on Emerging and Persistent Infectious Diseases (EPID):

- *EPID: Focus on Antimicrobial Resistance,* convened March 19–22, 2013, in Houston, Texas, U.S., in partnership with the Baylor College of Medicine.
- *21st Century Borders/Synthetic Biology: Focus on Responsibility and Governance*, convened December 4–7, 2012, in Tucson, Arizona, U.S., in partnership with the University of Arizona.
- *EPID: Focus on Societal and Economic Context*, convened July 8–11, 2012, in Fairfax, Virginia, U.S., in partnership with George Mason University.
- *EPID: Focus on Mitigation*, convened October 23–26, 2011, in Edinburgh, Scotland, U.K., in partnership with the University of Edinburgh.
- *EPID: Focus on Prevention*, convened June 5–8, 2011, in San Diego, California, U.S.
- *EPID: Focus on Surveillance*, convened October 17–20, 2010, in Warrenton, Virginia, U.S.
- *EPID: Global Perspectives*, convened December 6–9, 2009, in Tucson, Arizona, U.S., in partnership with the University of Arizona.

ISGP conferences and books on Food Safety, Security, and Defense (FSSD):

- *FSSD: Equitable, Sustainable, and Healthy Food Environments*, convened May 1–4, 2016 in Vancouver, British Columbia, Canada, in partnership with Simon Fraser University.
- *FSSD: Food Security and Diet-linked Public Health Challenges*, convened September 20–23, 2015 in Fargo, North Dakota, in partnership with North Dakota State University.
- *FSSD: Focus on Food and the Environment*, convened October 5–8, 2014, in Ithaca, New York, in partnership with Cornell University.
- *FSSD: Focus on Food and Water,* convened October 14–18, 2013, in Lincoln, Nebraska, U.S., in partnership with the University of Nebraska–Lincoln.
- *FSSD: Focus on Innovations and Technologies,* convened April 14–17, 2013, in Verona, Italy.
- *FSSD: Global Perspectives,* convened October 24, 2012, in Arlington, Virginia, U.S., in partnership with George Mason University.

ISGP conferences and books on Food Innovations (FI):

- *FI: Innovative Foods and Ingredients*, convened June 23–26 in Minneapolis, Minnesota, United States, with sponsorship from the U.S. Food and Drug Administration.

ISGP Academic Partnership (IAP) conferences and books:

- *Socioeconomic Contexts of Sustainable Agriculture,* convened October 14–15, 2016, in Danbury, Connecticut, in partnership with Western Connecticut State University.
- *Water and Fire: Impacts of Climate Change*, convened April 10–11, 2016, in Sacramento, California, in partnership with California State University.
- *Communicating Science for Policy*, convened August 10–11, 2015, in Durham, North Carolina, in partnership with Sigma Xi, The Scientific Research Society.
- *FSSD: Food Security: Production and Sustainability*, convened April 24–25, 2015, in St. Petersburg, Florida, in partnership with Sigma Xi, The Scientific Research Society, and Eckerd College.
- *FSSD: Safeguarding the American Food* Supply, convened April 10–11, 2015, in Collegeville, Pennsylvania, in partnership with Sigma Xi, The Scientific Research Society, and Ursinus College.

- *EPID: Focus on Pandemic Preparedness,* convened April 11–12, 2014, in Collegeville, Pennsylvania, U.S., in partnership with Ursinus College.

ISGP conferences and books on Science and Governance (SG):

- *Climate Impact on National Security (CINS–1, CINS–2A, CINS–2B),* convened November 28–December 1, 2016, April 3–4, 2017, and May 17–19, 2017 in partnership with the U.S. Army War College in Carlisle, Pennsylvania.
- *The Genomic Revolution,* convened September 6, 2014, in cooperation with the Parliamentary Office on Science and Technology of the British Parliament within the House of Lords. London, United Kingdom.

ISGP conferences and books on Global Challenges (GC):

- *ISGP Climate Change Program (ICCP): The Shore's Future: Living with Storms & Sea Level Rise*, convened November 20–21, 2015, in Toms River, New Jersey, in cooperation with the Toms River Working Group, Barnegat Bay Partnership, Barnegat Bay Foundation, and the Jay and Linda Grunin Foundation.
- *ICCP: Sea Level Rise: What's Our Next Move?*, convened October 2–3, 2015, in St. Petersburg, Florida, in cooperation with the St. Petersburg Working Group.
- *ISGP Climate Change Arctic Program (ICCAP): Sustainability Challenges: Coping with Less Water and Energy,* convened June 5, 2015, in Whittier, California, in cooperation with the Whittier Working Group.
- *ICCAP: Living with Less Water*, convened February 20–21, 2015, in Tucson Arizona, in cooperation with the Tucson Working Group.

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