Received: 8 March 2023 | Accepted: 8 March 2023

DOI: 10.1002/moda.5

ARTICLE

MODA WILEY

# 100 essential questions for the future of agriculture

**Yuming Hu[1] | Taolan Zhao[1] | Yafang Guo[1] | Meng Wang[1] | Kerstin Brachhold[1] | Chengcai Chu[2] | Andrew Hanson[3] | Sachin Kumar[4] | Rongcheng Lin[5] | Wenjin Long[6] | Ming Luo[7] | Jian Feng Ma[8] | Yansong Miao[9] | Shaoping Nie[10] | Yu Sheng[11] | Weiming Shi[12] | James Whelan[13,14] | Qingyu Wu[15] | Ziping Wu[16] | Wei Xie[11] | Yinong Yang[17] | Chao Zhao[18] | Lei Lei[1] | Yong-Guan Zhu[19,20] | Qifa Zhang[21]**

[1]Wiley-VCH GmbH, Weinheim, Germany

[2]State Key Laboratory for Conservation and Utilization of Subtropical Agro-Bioresources, College of Agriculture, South China Agricultural University, Guangzhou, China

[3]Horticultural Sciences Department, University of Florida, Gainesville, Florida, USA

[4]Rumen Biotechnology Laboratory, Animal Nutrition Division, ICAR-National Dairy Research Institute, Karnal, Haryana, India

[5]Key Laboratory of Photobiology, Institute of Botany, Chinese Academy of Sciences, Beijing, China

[6]School of Economics and Management, China Agricultural University, Beijing, China

[7]Guangdong Provincial Key Laboratory of Applied Botany & Agriculture and Biotechnology Research Center, South China Botanical Garden, Chinese Academy of Sciences, Guangzhou, China

[8]Institute of Plant Science and Resources, Okayama University, Kurashiki, Japan

[9]School of Biological Sciences, Nanyang Technological University, Singapore City, Singapore

[10]State Key Laboratory of Food Science and Technology, China-Canada Joint Lab of Food Science and Technology (Nanchang), Nanchang University, Nanchang, China

[11]China Center for Agricultural Policy, School of Advanced Agricultural Sciences, Peking University, Beijing, China

[12]State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, China

[13]State Key Laboratory of Plant Physiology and Biochemistry, College of Life Sciences, Zhejiang University, Hangzhou, Zhejiang, China

[14]Department of Animal, Plant and Soil Sciences, La Trobe University, Melbourne, Australia

[15]Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, China

[16]Economics Research Branch, Agri-Food Biosciences Institution, Belfast, UK

[17]Department of Plant Pathology and Environmental Microbiology and the Huck Institutes of the Life Sciences, The Pennsylvania State University, University Park, Pennsylvania, USA

[18]College of Marine Sciences, Fujian Agriculture and Forestry University, Fuzhou, China

[19]Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen, China

[20]State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Beijing, China

[21]National Key Laboratory of Crop Genetic Improvement and National Centre of Plant Gene Research (Wuhan), Hubei Hongshan Laboratory, Huazhong Agricultural University, Wuhan, China

**Correspondence**
Yuming Hu, Lei Lei, Yong-Guan Zhu and Qifa Zhang.
Email: yhu@wiley.com, llei@wiley.com, ygzhu@iue.ac.cn and qifazh@maild.hzau.edu.cn

## Abstract

The world is at a crossroad when it comes to agriculture. The global population is growing, and the demand for food is increasing, putting a strain on our agricultural resources and practices. To address this challenge, innovative, sustainable, and inclusive approaches to agriculture are urgently required. In this paper, we launched a call for Essential Questions for the Future of Agriculture and identified a priority list of 100 questions. We focus on 10 primary themes: transforming agri-food systems, enhancing resilience of agriculture to climate change, mitigating climate change through agriculture, exploring resources and technologies for breeding, advancing cultivation methods, sustaining healthy agroecosystems, enabling smart and controlled-environment agriculture for food security, promoting health and nutrition-driven agriculture, exploring economic opportunities and addressing social challenges, and integrating one health and modern agriculture. We emphasise the critical importance of interdisciplinary and multidisciplinary research that integrates both basic and applied sciences and bridges the gaps among various stakeholders for achieving sustainable agriculture.

**Key points**

- Growing demand and resource limitations pose a critical challenge for agriculture, necessitating innovative and sustainable approaches.
- The paper identifies 100 priority questions for the future of agriculture, indicating current and future research directions.
- Sustainable agriculture depends on interdisciplinary and multidisciplinary research that harmonises basic and applied sciences and fosters collaboration among different stakeholders.

## INTRODUCTION

Agriculture is essential for meeting human needs by providing food and a wide range of biomedical and industrial products. Despite yearly increases in agricultural production, about one in 10 people worldwide suffers from hunger, and many more lack sufficient food and suffer from micronutrient deficiencies and diet-related diseases.[1,2] Ongoing conflicts, climate change, pandemics, and rising inequality have far-reaching impacts on global agriculture, which in turn affects food security and human health. Promoting sustainable agriculture is crucial worldwide to increase incomes, achieve food security, improve nutrition, and balance natural ecosystems, not only for the 2030 Sustainable Development Goals and Paris Agreement but for the well-being of present and future generations. However, solving one problem without exacerbating others is a daunting and complex challenge. For example, a policy that lowers food prices to improve affordability may create difficulties for smallholder farmers. Providing a healthy diet to humans while balancing planetary health poses another significant global challenge. Moreover, there is often a gap between excellent scientific research on the bench, the complex challenges facing agriculture and the environment, and a lack of communication among multidisciplinary scientists, engineers, entrepreneurs, policymakers, farmers, and other stakeholders.

Multidisciplinary and interdisciplinary research is an emerging strategy aimed at shaping the future of agricultural research by integrating basic and applied sciences and bridging identified gaps for sustainable agriculture. To pursue this goal, we launched a call for "100 Essential Questions for the Future of Agriculture",[3] inviting diverse communities worldwide to participate starting from October 1, 2022. A previous paper about the top 100 questions of importance to the future of global agriculture was published almost a decade ago, with contributors primarily comprising experts and representatives from agricultural organizations.[4] Our collection was intended for a broad community, including scientists, engineers, farmers, entrepreneurs, policymakers, and the general public who are interested in shaping the future of agriculture. There were no limitations in place for who could participate in our call for "100 Essential Questions for the Future of Agriculture". By December 19, 2022, we received 419 questions from submitters in Asia, Africa, Europe, North America, South America, and Oceania, raising a range of issues and questions affecting agriculture. Following a thorough selection and analysis, we identified and compiled a priority list of 100 essential questions critical to global socioeconomic development and improving human well-being (Figure 1, Supplementary Table 1).

## RESULTS AND DISCUSSIONS

### Transforming agri-food system

The Transforming Agri-Food Systems initiative aims to create a more sustainable and equitable agriculture and


**FIGURE 1** The word frequency analysis of the 100 essential questions for the future of agriculture. The size of each word in the figure correlates with its frequency, while the colour is randomly applied from a preset selection (see Supplementary Table 2).

food system by addressing the root causes of challenges such as environmental degradation, social inequality, and economic instability.[5] The initiative brings together multiple stakeholders across the value chain to develop a shared vision and goals for transforming the system, recognising the need for a systemic approach that addresses social, economic, and environmental dimensions of sustainability. This involves implementing sustainable production practices, improving market access and value chains, promoting equitable governance, and enhancing consumer awareness.

We have chosen two questions pertaining to this subject.

1. What are the main drivers of the transformation of global, regional, and national agri-food systems?
2. To address current challenges in agri-food systems, is it advisable to adopt a strategy that combines farming intensification with a reduction in food consumption levels in developed and emerging nations?

The first comprehensive question is a complex issue, as numerous factors contribute to the transformation of agri-food systems at global, regional, and national levels. These factors include climate change, demographic shifts, technological advancements, evolving consumer preferences, globalisation and trade, and changes in policies and regulations.[5] For the purpose of this discussion, we will begin by examining the impact of climate change.

## Enhancing resilience of agriculture to climate change

Climate change has a significant impact on agriculture, which cannot be neglected. The changes in temperature, precipitation, and the increasing frequency of extreme weather events as well as pest and disease outbreaks have significant implications for agricultural productivity. Although there are some positive effects, in most scenarios these factors can negatively affect agricultural production, soil health, and water accessibility, leading to food security issues. It is essential to both mitigate the effects of climate change on agriculture and explore how agriculture can contribute to mitigating climate change.

Six selected questions are focussed on this topic.

3. How shall we understand and predict the impacts of climate change on agri-food systems?
4. What are the cost-effective methods to improve crop yield in arid and semi-arid areas?
5. What are the most effective environmentally-sustainable strategies to maintain or increase food production in soils affected by rising salinity?
6. How can the overall climate resilience of crop/agricultural systems be increased, beyond just enhancing the resilience of individual crops?
7. How can biological invasions, caused by climate change, be effectively managed?
8. What are the potential long-term implications of climate change on land use and related policies?

Cynthia Rosenzweig received the 2022 World Food Prize for her contributions to understanding the impacts of climate on food systems.[6] Climate-smart agriculture is increasingly exploring this area to increase resilience to climate risks. A holistic approach, including diversification, can be effective in reducing dependence on a single resource.[7] Strategies such as climate-resilient crop varieties, early detection of invasive species, promoting native species, maintaining ecosystem diversiy, and changes in agricultural practices and land use patterns are of interest.

## Mitigating climate change through agriculture

Agriculture is both a victim and a major contributor to climate change. Approximately 20% of global greenhouse gas (GHG) emissions come from agriculture and related land use. Agricultural activities such as crops and livestock production release significant amounts of non-$CO_2$ emissions such as methane ($CH_4$) and nitrous oxide ($N_2O$), with livestock production contributing two-thirds of this total. In particular, $CH_4$ emissions from enteric fermentation in the digestive systems of ruminant livestock remain the single largest component of farm-gate emissions.[8] To reduce climate change impacts, it is important to explore strategies for mitigating GHG emissions in livestock and agri-food transformation.

Nine selected questions are focussed on GHG emissions in livestock and agri-food transformation.

9. How can we reduce greenhouse gas emissions in agriculture, especially in livestock production, food processing, and manufacturing?
10. Will the trend of expanding animal production in developed and emerging countries be reversed due to climate change challenges and concerns for human health related to livestock products?
11. How do the concepts of "carbon footprint," "carbon sink," and "carbon trade" relate to livestock production and research?
12. How to overcome the main barriers in achieving carbon neutrality, balance, or even negativity in agri-food systems?
13. Is cultured meat the path to carbon neutrality in agriculture?
14. How can soil be utilised to generate long-term carbon storage credits?
15. How long do 'recalcitrant' forms of plant carbon such as suberin and sporopollenin persist in agricultural soils?
16. What are the most effective strategies to reduce soil nitrogen emissions?
17. Can soil carbon sequestration improve the quality of cultivated land?

## Exploring resources and technologies for breeding

Germplasm resources are the "chips" of modern agriculture, and also key to solving various agriculture related issues including climate change. With the help of high-throughput and intelligent phenotyping technology, researchers can quickly identify crop varieties with desirable traits and systematically collect and store them for future use. The integration of traditional genetic methods and high-throughput sequencing technology allows scientists to uncover the genetic code of desirable traits and the molecular mechanisms behind them. This knowledge provides a theoretical basis for developing customised crop varieties to suit specific needs. The application of new technologies such as protein directed evolution, synthetic biology, digitalisation, and artificial intelligence has led to breakthroughs in molecular design breeding. In the future, agriculture will prioritise the balance of high yield, high quality, high efficiency, environmental sustainability, and full integration with the industry.

In this session, we selected 24 questions mainly from the field of crop breeding, animal husbandry, and aquatic products.

18. What are the most effective and intelligent phenotyping strategies in breeding?
19. What are the best approaches for collecting, protecting, fully exploiting, and utilising germplasm resources?
20. What approaches are useful to transfer desirable genes from wild resources to cultivated varieties?
21. How to achieve breakthrough germplasm innovation, the mining of excellent genes and stable inheritance of crops?
22. How to use epigenetic mechanisms to expand gene resources, regulate plant regeneration, and promote crop performance?
23. What is the formation mechanism of crop heterosis?
24. What are the challenges of designing ideal phenotypic crops from genotype?
25. Do we need to domesticate new crops to deal with the changing climate?
26. Can new crops be created by artificial design?
27. How does synthetic biology contribute to the enhancement of breeding and crop development?
28. What are the methods for enhancing the properties of known proteins to effectively enhance crop traits?
29. How to develop directed evolution technology of key proteins?
30. What are the methods to reduce the breeding cycle duration in animal husbandry?
31. How to promote molecular breeding of aquatic organisms?
32. What are the directions for creating a more efficient next-generation breeding technology that surpasses molecular breeding?
33. How to realize the technological innovation and system establishment of digital breeding?
34. What are the steps necessary to use artificial intelligence for genome design and agricultural breeding?
35. What strategies can be implemented to overcome the factors that restrict crop yield and achieve the highest possible yield?
36. How to coordinate the relationship among crop yield, quality, and efficiency?
37. How to convert annual crops into perennial crops?
38. What are the most effective ways to increase photosynthesis efficiency?
39. How to increase crop resistance to various stresses while maintaining or even improving the yield and quality?
40. In what ways can future breeding techniques address the challenges posed by climate change and the increasing demand for nutritious crops?
41. What is the appropriate level of capital investment required for the breeding industry?

## Advancing cultivation methods

To achieve high-quality yields of agricultural products, it is essential to not only have excellent germplasm resources but also advanced cultivation methods. Traditional agriculture, which often prioritises high yields, tends to excessively apply chemical fertilizers and pesticides, resulting in significant harm to the agricultural environment. In modern agriculture, it is crucial to fully understand the mechanism of crop nutrition utilization, greatly improve crop nutrient utilization efficiency, implement precise application of green fertilizers and pesticides, and establish a sustainable and environmentally friendly agricultural system.

### Nutrition utilization efficiency

42. How to achieve efficient and coordinated utilization of plant resources, such as light, water, nutrients, among others?
43. What are the underlying genetic foundation, regulatory circuitry, and transportation mechanisms that enable crops to effectively utilise essential mineral nutrients, including carbon, nitrogen, phosphorus, and other micronutrients?
44. What strategies are efficient in improving the nutrient utilization efficiency?
45. What approaches can be taken to achieve equilibrium fertilization of several essential nutrients?
46. To what extent can nutrient-efficient crops increase crop yield, reduce environmental risks, and improve economic profitability?
47. What are the techniques and methods that can be employed to enhance the nutritional value of staple crops, therefore producing biofortified foods?

### Fertiliser and pesticides

48. How to enhance the efficiency, eco-friendliness, and sustainability of fertilization inputs?
49. What is the suitable amount of fertiliser recommended for farmland based on factors such as crop type, soil characteristics, and environmental impact?
50. How to develop precision nutrient fertilizers and pesticides, including nano-fertilizers and nano-pesticides, that have minimal environmental impact?
51. What are the methods for developing green nitrogen fertiliser to substitute urea?
52. What are the strategies for identifying novel targets for prevalent crop diseases and developing eco-friendly pesticides?

## Sustaining healthy agroecosystems

The productivity and sustainability of agriculture rely on a healthy agroecosystem, which, in turn, depends on healthy soil as a cornerstone of farming systems. Healthy soil requires good structure and drainage, sufficient depth for root growth, appropriate and balanced nutrient levels, minimal populations of weeds, pests, and pathogens, thriving populations of beneficial organisms, absence of toxins, and resilience to adverse conditions. Moreover, a deeper understanding of underlying mechanisms is necessary to provide new opportunities for reducing the application of chemical fertilizers and agricultural chemicals while sustaining agricultural productivity.

To establish a sustainable soil-food-environment-health system, the following critical questions have been chosen.

53. How to measure soil health effectively?
54. How can we manipulate soil microbes in situ and facilitate the interaction between crops and beneficial microorganisms in soil, with the aim of enhancing crop growth, improving plant resistance, and promoting sustainability in modern agriculture?
55. What is the mechanism behind the interaction between crops and beneficial microorganisms in soil?
56. What are some effective methods for preventing and mitigating soil salinisation?
57. What is the mechanism by which soil microorganisms are involved in the transformation of organic and inorganic nitrogen?
58. How to understand the ecological function of viruses in agricultural systems?
59. What is the future outlook for the development of soil biomimetic materials?

Some soil health issues, such as heavy metal pollution, have been long-standing concerns, while others, such as nanomaterials, microplastics, antibiotics, and their resistance genes, have gained increasing attention in recent years. Furthermore, certain nutrients can have both positive and negative effects, with the optimal amount being crucial. As a result, we are still working to find solutions to the problem of agricultural land pollution in order to ensure food safety.

60. What are some effective methods for remediating heavy metal contamination in agroecosystems?
61. What is the fate of novel pollutants such as nanomaterials and microplastics in the crop-soil-microbial system?
62. How to reduce the cost of treating agriculturally contaminated soils while increasing the effectiveness of the treatment?
63. How to reduce phosphorus pollution and address the issues related to phosphorus scarcity?
64. What are the strategies for reducing or replacing the usage of antibiotics in the livestock industry?
65. How to address the challenge of resistance genes resulting from the use of antibiotics in livestock and poultry, and their manure and organic waste?
66. Which biomolecules act as switches for plant signal transduction and respond to various mechanical, environmental, and chemical cues?

In the agroecosystems, agricultural waste can cause severe pollution of air, water, and contribute to global warming. We selected one question related to waste utilization, because proper waste management is crucial for minimising environmental pollution and promoting sustainable agriculture.

67. How to improve the utilization of agricultural waste?

## Enabling smart and controlled-environment agriculture for food security

The problems of pollution and the increasing demand for food while ensuring food security and sustainability requires effective use of natural resources and advancements in technology, such as artificial intelligence, analytics, and connected sensors, which can improve the efficiency of water and inputs, increase yields, and build resilience. However, agriculture needs to embrace a digital transformation to realize these benefits. Facility management can also streamline support processes and reduce operating costs, while the use of renewable energy sources can mitigate food and environmental pollution problems and ensure continuity of energy supply. To achieve agricultural sustainability, a multidimensional approach is necessary, which is related to the following questions.

68. How to develop and implement data science and information technology in the agriculture industry?
69. In what scenarios can AI technology be seamlessly integrated with digital agriculture?
70. How to achieve intelligent phenotyping and genome technology in livestock and poultry breeding?
71. How to address the issues of excessive energy consumption and high costs in controlled-environment agriculture?

72. What are and how to develop the next generation of sensing technologies in agriculture?
73. How can agricultural automation be applied in various contexts or situations to promote the realization of sustainable development goals?
74. What strategies can be employed to establish disaster mechanisms and precise early warnings for significant transboundary migratory pests?

## Promoting health and nutrition-driven agriculture

The main purpose of agriculture and food systems is to ensure nutrition security by supplying nutritious and affordable foods, but despite impressive gains in agricultural production, a large population worldwide suffers from nutritional imbalances. Millions suffer from deficiencies in energy, protein, and trace nutrients such as vitamin A, iron, and iodine, especially in undeveloped countries. Improvements in agricultural production can help combat malnutrition, but aligning agriculture with nutrition objectives requires research and development specialists to contribute to integrated agriculture-health programs. Four comprehensive questions are chosen to promote health and nutrition-driven agriculture.

75. What are the methods to enhance soil health and promote human health through agriculture?
76. How to define and achieve a healthy diet?
77. How to fulfil human nutrition, health, and culinary preferences through personalised and appetising food?
78. What are the current and future development trajectories of cellular agriculture?

## Exploring economic opportunities and addressing social challenges

Achieving food security and human nutrition is not only a matter of ensuring enough food, but also requires addressing the social and economic challenges that prevent access to nutritious food. We collected dozens of questions related to addressing these social challenges and leveraging economic opportunities for promoting sustainable agriculture and the relevant technologies. By achieving sustainable agriculture, we can improve social equity and ensure economic prosperity for both producers and consumers. We hope that the selected questions will provide valuable insights into the social and economic dimensions of modern agriculture and inspire new ideas for promoting the well-being of humanity.

79. How to make the balance between agricultural development and urbanisation?
80. What approaches can be utilised to address the paradox of a growing population with limited agricultural resources?
81. How to attain a sustainable food supply?
82. How trade can be used to safeguard food security at both the global and national levels?
83. What strategies can be employed to reconcile global value chains with agricultural resource flows?
84. How to increase and stabilise farmers' incomes amidst the challenges of climate change and local social unrest?
85. What are the key challenges and opportunities in linking global and national policies between agriculture and human nutrition?
86. How can the policies be better integrated to promote improved nutrition outcomes globally?
87. What measures can be implemented to both promote the industrialisation of genetically modified crops and ensure effective regulation of genetically modified agricultural products?
88. How to transit livestock and dairy farming, especially ruminant farming, to more sustainable industries such as arable farming or other viable alternatives?
89. How to protect and sustainably use marine fishery resources?
90. What are the directions to develop novel food production techniques and resources?
91. How to reduce food loss and waste?
92. In terms of technology and economy, what degree of intelligence is required for agricultural robots to adapt to agricultural production?
93. What is the significance of artificial intelligence in the agricultural sector?
94. How can the agriculture sector leverage Web 3 technology to enhance sustainability, efficiency, and productivity while also tackling issues such as food security, environmental impact, and social and economic equity?
95. Who will farm in the future?

## Integrating one health and modern agriculture

Agriculture is more than social and economic well-being. The concept of One Health recognises the interdependence of human, animal, and environmental health, and emphasises the importance of collaboration between multiple sectors to address complex health challenges. In recent years, the agricultural sector has undergone significant modernisation to meet the growing demand for food, but this has brought new challenges to the One Health approach, including the emergence of zoonotic diseases and environmental degradation. Therefore, we have seen several questions aiming to explore the challenges involved in integrating modern agriculture with the One Health concept, and to develop a framework to ensure future food security by promoting sustainable practices that consider the health and well-being of humans, animals, and the environment.

96. What are the challenges involved in integrating the modern agricultural approach with the One

Health concept? What framework can be developed to address these challenges and ensure future food security?
97. What priority efficiency goals should be set for livestock production systems to ensure they can meet the demand for livestock products in a sustainable and economically viable manner while also considering environmental concerns?
98. How to prevent the transmission of animal epidemics to humans?
99. What strategies can be employed to attain sustainable and healthful meat consumption practices that are also environmentally friendly?
100. How to achieve ecological equilibrium in agriculture, enabling plants, animals, and microorganisms to coexist harmoniously?

## CONCLUSIONS

The classification of the 100 selected questions is challenging due to their complex and integrative nature (Figure 1). In addition to the 10 primary themes, we identified four key perspectives that enable a holistic understanding of agricultural systems: Resource & Environment, Agricultural Production, Nutrition & Health, and Social & Economic Impacts (Figure 2). These perspectives acknowledge that agriculture goes beyond just producing food and other vital products (e.g., fibre, biofuels, medicine etc.), and has significant impacts on the environment, human health, and society. Natural resources are the bedrock of agriculture, and managing them sustainably is essential to maintain a healthy and productive agricultural system for long-term viability. Agricultural production lies at the heart of farming practices, and it should be carried out efficiently and sustainably to optimise productivity while minimising negative environmental impacts. Nutrition and health are primary objectives of agriculture, encompassing human and planetary health, as well as social and economic aspects. Achieving these objectives necessitates a multidisciplinary approach that integrates knowledge from diverse fields and applies cutting-edge science and technology. By effectively managing resources, promoting sustainable agricultural production, and prioritising nutrition and health, we can ensure long-term economic and societal success. This is why we find the 100 essential questions for the future of agriculture intriguing, and we eagerly anticipate discovering the answers.


**FIGURE 2** The integrative landscape of the 100 essential questions for the future of agriculture. We have identified four key perspectives for comprehensively understanding agricultural systems: Resource & Environment, Agricultural Production, Nutrition & Health, and Social & Economic Impacts. These perspectives acknowledge that agriculture has significant impacts on the environment, human health, and society beyond food production. Sustainable management of natural resources is essential to ensure efficient agricultural production. Agricultural products are closely linked to human nutrition and health, requiring multidisciplinary approaches that integrate diverse fields and cutting-edge technology. By managing resources, promoting sustainable agriculture, and prioritising nutrition and health, we can ensure long-term economic and societal success.

## METHODS

### Data collection

The questionnaire was available for 80 days beginning on October 1, 2022. It was initially posted on ModA: 100 Questions for the Future of Agriculture (wiley.com) journal website, allowing contributors of different nationalities and experiences to submit questions along with their names and institutes. Alternatively, anonymous submissions were also accepted. The questionnaire was promoted on various websites and social media platforms, including WeChat, and Twitter, targeting diverse audiences and participants. Additionally, it was distributed via email to authorised distribution lists of agricultural scientists worldwide.

In total, 419 questions had been collected.

### Question selection

A selection board (the authors of this article), consisting of distinguished authorities, editorial board members, and the editorial office, was responsible for evaluating all submissions and selecting the final hundreds for publication.

Initially, the editorial office pre-screened the original list of 419 questions, eliminating any that were duplicated or ambiguous. This resulted in a list of 339 questions, which were then sorted into four main categories: Resource & Environment, Agricultural Production, Nutrition & Health, and Social and Economic Impacts.

The importance level of these questions was rated on a scale of 1–5, ranging from low general interest to critically important. The questionnaires were distributed to 19 experts representing the four key areas. Each expert rated the questions in their focus area independently and had the opportunity to raise additional important questions, provide comments, and communicate with the editorial office throughout the process. Afterwards, all the questions were pooled and ranked based on their scores, and the top-ranked questions were categorised into 10 primary themes as shown in the main text. The editorial office then re-evaluated each question, along with other questions that addressed similar issues, based on onsite or virtual panel discussions. In some cases, questions were combined and rephrased.

All questions were screened anonymously without considering the person who submitted them. Finally, the panel agreed on the final list of 100 questions, with the final wording chosen carefully by the editorial office.

## Word frequency analysis

To generate Figure 1, we utilised NVivo 12 software and conducted a Word Frequency query to identify the 50 most frequently mentioned words among the selected 100 questions. The text grouping level was set to "With specializations."

## AUTHOR CONTRIBUTIONS

**Yuming Hu**: Conceptualisation (equal); Data curation (equal); Formal analysis (equal); Investigation (equal); Methodology (equal); Project administration (equal); Writing – original draft (equal); Writing – review & editing (equal). **Taolan Zhao**: Investigation (equal); Resources (equal); Writing – original draft (equal). **Yafang Guo**: Investigation (equal); Resources (equal); Writing – original draft (equal). **Meng Wang**: Data curation (equal); Investigation (equal); Visualisation (equal). **Kerstin Brachhold**: Writing – review & editing (equal). **Chengcai Chu**: Investigation (equal); Resources (equal). **Andrew D. Hanson**: Investigation (equal); Resources (equal). **Sachin Kumar**: Investigation (equal); Resources (equal). **Rongchen Lin**: Investigation (equal); Resources (equal). **Wenjin Long**: Investigation (equal); Resources (equal). **Ming Luo**: Investigation (equal); Resources (equal). **Jian Feng Ma**: Investigation (equal); Resources (equal). **Yansong Miao**: Investigation (equal); Resources (equal). **Shaoping Nie**: Investigation (equal); Resources (equal). **Yu Sheng**: Investigation (equal); Resources (equal). **Weiming Shi**: Investigation (equal); Resources (equal). **James Michael Whelan**: Investigation (equal); Resources (equal). **Qingyu Wu**: Investigation (equal); Resources (equal). **Ziping Wu**: Investigation (equal); Resources (equal). **Wei Xie**: Investigation (equal); Resources (equal). **Yinong Yang**: Investigation (equal); Resources (equal). **Chao Zhao**: Investigation (equal); Resources (equal). **Lei Lei**: Conceptualisation (equal); Investigation (equal); Methodology (equal); Project administration (equal); Supervision (equal); Validation (equal); Writing – original draft (equal); Writing – review & editing (equal). **Yong-Guan Zhu**: Conceptualisation (equal); Investigation (equal); Resources (equal); Supervision (equal); Validation (equal); Writing – review & editing (equal). **Qifa Zhang**: Conceptualisation (equal); Investigation (equal); Resources (equal); Supervision (equal); Validation (equal); Writing – review & editing (equal).

## ACKNOWLEDGEMENTS

The authors would like to express their gratitude to all those who submitted questions, including the many anonymous contributors, as well as individuals listed who contribute to the selected questions: Olajide Agnes, Landmark University; Xunfeng Chen, Jiangsu Universitiy; Peipei Dan, Central South University of Forestry and Technology; Qiang Dong, Northwest A&F University; Xiangyan Feng, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences; Jianguo Gao, Xinjiang University; Xiao Guo, Sichuan University; Shengbo He, Huanan Agricultural University; Xiao He, Beijing University of Chemical Technology; Qun Hu, Yangzhou University; Sivendra Joshi, Govind Ballabh Pant University of Agriculture and Technology; Feng Ju, Westlake University; Xinxin Li, Tufts University; Dehua Liao, Fujian Agriculture and Forestry University; Haoyu Liu, Yangzhou University; Lianliang Liu, Ningbo University; Qikun Liu, Peking University; Ranhong Liu, Guanxi University; Teo Chee Loong, Agri Season Private Limited; Santosh Subhash Palmate, Texas A&M University; Yizhou Qin, China Agricultural University; Zhangcai Qin, Sun Yat-sen University; Brian Reid, University of East Anglia; Paolo Ruisi, University of Palermo; Benjamin Scott, University of Saskatchewa; Yu Shi, Henan University; Sanyuan Tang, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences; Cristian C. Villa, Universidad del Quindio; Song Wang, Lushan Botanical Garden, Chinese Academy of Sciences; Zhong Wei, Nanjing Agricultural University; Yuliang Xu, Zhejiang University; Bing Yang, Sichuan Academy of Giant Panda; Heng Yin, Dalian Institute of Chemical Physics, Chinese Academy of Sciences; De Yu, Hunan Agricultural University; Ziyi Yu, Nanjing Tech University; Xi Zhou, China Agricultural University; Kaijing Zuo, Shanghai Jiao Tong University; Han Chun, Fudan University. Thanks to Minmin Jia (John Wiley & Sons, Inc.) and Wanyu Qi (Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences) for their contributions in building up the webpage and question forms. Thanks to Zhao Zha (John Wiley & Sons, Inc.) for the initial discussions.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

All data and materials used in this study are available from the corresponding authorsupon reasonable request.

## ORCID

*Yuming Hu* https://orcid.org/0000-0002-9151-7114
*Taolan Zhao* https://orcid.org/0000-0002-0981-6255
*Yafang Guo* https://orcid.org/0000-0002-7374-1788

*Kerstin Brachhold* https://orcid.org/0000-0002-2319-7120
*Chengcai Chu* https://orcid.org/0000-0001-8097-6115
*Andrew Hanson* https://orcid.org/0000-0003-2585-9340
*Sachin Kumar* https://orcid.org/0000-0003-1233-9450
*Rongcheng Lin* https://orcid.org/0000-0001-8346-3390
*Wenjin Long* https://orcid.org/0000-0003-1419-2544
*Ming Luo* https://orcid.org/0000-0002-6912-7638
*Jian Feng Ma* https://orcid.org/0000-0003-3411-827X
*Yansong Miao* https://orcid.org/0000-0003-1551-7873
*Shaoping Nie* https://orcid.org/0000-0002-2412-4679
*Yu Sheng* https://orcid.org/0000-0002-8467-6213
*James Whelan* https://orcid.org/0000-0001-5754-025X
*Qingyu Wu* https://orcid.org/0000-0003-3064-2445
*Ziping Wu* https://orcid.org/0000-0003-3661-0110
*Wei Xie* https://orcid.org/0000-0001-6205-4301
*Yinong Yang* https://orcid.org/0000-0002-2698-1754
*Chao Zhao* https://orcid.org/0000-0003-1096-632X
*Lei Lei* https://orcid.org/0000-0003-4803-4763
*Yong-Guan Zhu* https://orcid.org/0000-0003-3861-8482
*Qifa Zhang* https://orcid.org/0000-0003-2693-2685

## REFERENCES

1. The sustainable development goals report 2022. https://unstats.un.org/sdgs/report/2022/
2. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, et al. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. 2019;393(10170):447–92. https://doi.org/10.1016/S0140-6736(18)31788-4
3. 100 Essential questions for the future of agriculture. https://onlinelibrary.wiley.com/page/journal/27514102/homepage/100-questions-for-agriculture-2022
4. Pretty J, Sutherland WJ, Ashby J, Auburn J, Baulcombe D, Bell M, et al. The top 100 questions of importance to the future of global agriculture. Int J Agric Sustain. 2011;8(4):219–36. https://doi.org/10.3763/ijas.2010.0534
5. Agri-food systems transformation: new, ambitious framework proposed to monitor progress. https://www.fao.org/newsroom/detail/new-framework-proposed-to-monitor-food-systems-progress/en
6. 2022 Rosenzweig. The world food prize - improving the quality, quantity and availability of food in the world. https://www.worldfoodprize.org/en/laureates/2022_rosenzweig/
7. Hertel T, Elouafi I, Tanticharoen M, Ewert F. Diversification for enhanced food systems resilience. Nature Food. 2021;2(11):832–34. https://doi.org/10.1038/s43016-021-00403-9
8. Emissions due to agriculture. Global, regional and country trends 2000–2018. FAO; 2021. https://www.fao.org/policy-support/tools-and-publications/resources-details/en/c/1382716

## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

**How to cite this article:** Hu Y, Zhao T, Guo Y, Wang M, Brachhold K, Chu C, et al. 100 essential questions for the future of agriculture. Modern Agriculture. 2023;1(1):4–12. https://doi.org/10.1002/moda.5