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1 **The One Hundred Most Important Questions Facing**

2 **Plant Science Research**

3
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42 **Summary**

43 Plant biology is more important today than ever. Significant advances are required if we are
44 to meet the escalating pressure for food, fuel, fibre and other plant products, and address the
45 problems generated by climate change in a sustainable way, against a backdrop of an ever
46 increasing and more prosperous human population. Scientific research has begun to focus its
47 efforts towards these grand challenges, but it is not clear that the full range of challenges
48 facing plant science is known or has been prioritised. What questions should the next
49 generation of plant biologists address? Here we suggest, with brief explanations, our list of
50 the most important questions facing plant science research today. We aim to stimulate
51 discussion, encouraging plant scientists to think beyond the limits of their own specific sub-
52 fields about the most important research that can conceivably be done, the most promising
53 approaches that might successfully be applied, and the most significant discoveries that can
54 possibly be made.

55

56

57 **Introduction**

58 Plant biology is more important today than ever. Significant advances are required if we are
59 to meet the escalating pressure for abundant safe and nutritious food, renewable fuel, and
60 fibre, address the problems generated by climate change, and preserve habitats, all against a
61 backdrop of an ever increasing and more prosperous human population. These global
62 challenges can only be met in the context of a strong fundamental understanding of plant
63 biology and ecology, and the translation of this knowledge into field-based solutions.

64

65 Scientific research has begun to focus its efforts towards these grand challenges, but it is not
66 clear that the full range of challenges facing plant science is known or has been prioritised.
67 What questions should the next generation of plant biologists be addressing? To start to
68 answer this question we set out to compile a list of the one hundred most important questions
69 facing plant science research.

70

71 We had three main goals: 1. We aimed to stimulate discussion amongst the plant science and
72 related communities, and identify areas of research that would have a substantial impact. 2.
73 We hoped to encourage plant scientists to think beyond the limits of their own specific sub-
74 fields about the most important research that could possibly be achieved. 3. We sought to
75 illustrate the importance and potential of plant science to the broader public. This paper
76 addresses aims 1 and 2, but questions were selected with all three aims in mind. This is
77 intended to be a starting point. Research priorities and challenges change continuously and
78 unpredictably as new concerns and needs arise, and new knowledge is revealed, and it will be
79 important to review and reassess this list in the future. Here we present, with brief
80 explanations of their significance, our list of the most important questions facing plant
81 science research today.

82

83 **Methods**

84 Questions were invited online over a three-month period at
85 <http://www.100plantsciencequestions.org.uk/index.php>. The web site was publicised by

86 email using distribution lists of plant scientists in the UK and abroad, on web sites aimed at
87 plant scientists and farmers, and in a press release, which led to coverage by some news
88 websites and newspapers. The questions submitted to the web site are listed in full at
89 <http://www.100plantsciencequestions.org.uk/viewquestions.php>, along with the names of the
90 people who submitted them, apart from a few cases where submitters chose to be anonymous.
91 The online consultation process allowed input from contributors with a range of nationalities
92 and experience. The full list of 350 questions was provided in advance to a panel of 15
93 individuals (Steve Barnes, Ruth Bastow, Mark Chase, Matthew Clarke, Claire Grierson,
94 Alistair Fitter, Don Grierson, Keith Edwards, Graham Jellis, Jonathan Jones, Sandy Knapp,
95 Giles Oldroyd, Guy Poppy, Paul Temple, Roger Williams) representing the academic,
96 commercial and public service communities that produce or benefit from plant science
97 research, and able to take part in a two-day workshop at Bristol, UK in 2009. During the
98 process the list was reduced to 96 questions by mutual agreement, which we hope will plant
99 more local variants particularly adapted to research and societal priorities in both the
100 developing and developed world. Prior to the panel meeting the full list of 350 submitted
101 questions was roughly organised into groups according to topic. Each panel member
102 independently selected their top twenty questions and these lists were combined. During this
103 process other possible questions under each topic were suggested and considered for
104 inclusion. Each question selected by a panel member was discussed by the whole panel,
105 along with other questions that addressed similar issues. The most important question on each
106 topic was agreed upon by the whole panel and a final wording chosen. In some cases the
107 panel decided that a new question was required, and the panel worked together to produce the
108 wordings for these new questions.

109

110 **Results and Discussion**

111 As plant science is a broad and diverse field, we provide brief explanations of the
112 background, context and prospects for addressing each question with the aim of making the
113 questions accessible to the broadest possible audience.

114 There is no ideal way to divide the questions into topic areas. Many questions inevitably span
115 more than one category, and some particularly substantial topics merit multiple questions.
116 For the purposes of this paper the panel decided to categorise the questions into five broad
117 areas that reflect the breadth and depth of plant research discussed during the two day
118 workshop: Society, Environment and Adaptation, Species Interactions, Understanding and
119 Utilizing Plant Cells, and Diversity.

120

121

122 **A. Society**

123 Here we consider the overall significance of plants and plant science to human society in
124 general. We open with ten questions that the panel felt encapsulated the most burning societal
125 issues that should be addressed by plant science, followed by other societal questions selected
126 by the panel. More specific biological questions in plant science follow in later sections.

127

128 **The Ten Questions Most Important to Society**

129 **A1. How do we feed our children's children?**

130 By 2050 the world population will have reached approximately 9 billion people. This will
131 represent a tripling of the world population within the average lifetime of a single human
132 being. The population is not only expanding, but also becoming more discerning, with greater
133 demands for energy intensive foods such as meat and dairy. Meeting these increasing food
134 demands over the years to come requires a doubling of food production from existing levels.
135 How are we going to achieve this? Through the cultivation of land currently covered in
136 rainforests, through enhanced production from existing arable land or by changing people's
137 habits to change food consumption patterns and reduce food waste? The reality is probably a
138 combination of all three. However, if we are to reduce the impact of food production on the
139 remaining wilderness areas of the planet then we need significant investment in agricultural
140 science and innovation to ensure maximum productivity on existing arable land.

141

142 **A2. Which crops must be grown and which sacrificed, to feed the billions?**

143 The majority of agricultural land is used to cultivate the staple food crops wheat, maize and
144 rice, the oil rich crops soy (*Glycine max*), canola, sunflower (*Helianthus* spp.) and oil palm
145 (*Elaeis guineensis*) and commodity crops such as cotton (*Gossypium* spp.), tea (*Camellia*
146 *sinensis*) and coffee (*Coffea* spp.). As the world population expands and as demand for meat
147 increases, there is a growing demand for staples and oil rich crops for both human
148 consumption and animal feed. Without significant improvements in yields of these basic
149 crop plants, we will experience a squeeze on agricultural land. It is therefore essential that we
150 address the yield gap; the difference between future yield requirements and the yields
151 available with current technologies, management and gene pools. Otherwise we may be
152 forced to choose between production of staple food crops to feed the world population and

153 the production of luxury crops, such as tea, coffee, cocoa (*Theobroma cacao*), cotton, fruits
154 and vegetables.

155

156 **A3. When and how can we simultaneously deliver increased yields and reduce the**
157 **environmental impact of agriculture?**

158 The first green revolution of the late 1950s and early 1960s generated unprecedented growth
159 in food production. However these achievements have come at some cost to the environment
160 and they will not keep pace with future growth in the world population. We need creative and
161 energetic plant breeding programs for the major crops worldwide, with a strong public sector
162 component. We need to explore all options for better agronomic practice, including better soil
163 management and smarter intercropping, especially in the tropics. Finally, we need to be able
164 to deploy existing methods of genetic modification that reduce losses to pests, disease and
165 weeds, improve efficiency of fertilizer use and increase drought tolerance. We also need to
166 devise methods to improve photosynthetic efficiency, and move the capacity for nitrogen
167 fixation from legumes to other crops. These are all desirable, and with public support,
168 feasible goals.

169

170 **A4. What are the best ways to control invasive species including plants, pests and**
171 **pathogens?**

172 Invasive species are an increasingly significant threat to our environment, economy, health
173 and well-being. Most are non-indigenous (evolved elsewhere and accidentally introduced)
174 and have been removed from the constraints which were regulating their growth in their
175 native habitat. The best method of control is to prevent establishment in the first place or to

176 quickly identify establishment and adopt an eradication programme. However if an invasive
177 species becomes established many of the options for removal can cause environmental
178 damage for example chemical control or mechanical excavation. Biological control
179 (introduction of a natural predator/pathogen) can work well as long as the control organism
180 targets the invasive species. Otherwise there is a risk that the control organism might also
181 become an invasive species. Alternatives, such as manipulating existing natural enemies
182 and/or the environment to enhance biological control, are also being developed. Sustainable
183 solutions are required if we are to deal with the continually growing problem of invasive
184 species.

185

186 **A5. Considering two plants obtained for the same trait, one by genetic modification**
187 **and one by traditional plant breeding techniques, are there differences between**
188 **those two plants that justify special regulation?**

189 The products of traditional plant breeding are subject to no special regulations, even though
190 the wild sources of germplasm often used by breeders may contain new components that
191 have not been assessed before. A plant derived by genetic modification, however, is highly
192 regulated, even though the target genotype and the modification itself may both be highly
193 characterised and accepted as innocuous for their intended use. This is a major exception to
194 the norm for safety regulation in food and other areas, which is normally based on the
195 properties of the object being regulated. It is important for food safety and for the public's
196 perception of science and technology in general to establish whether there are any objective
197 differences between these groups of products that justify the different approaches to their
198 regulation.

199

200 **A6. How can plants contribute to solving the energy crisis and ameliorating global**
201 **warming?**

202 Plants use solar energy to power the conversion of CO₂ into plant materials such as starch
203 and cell walls. Plant material can be burnt or fermented to release heat energy or make fuels
204 such as ethanol or diesel. There is interest in using algae (unicellular aquatic plants) to
205 capture CO₂ emissions from power stations at source. Biomass cellulose crops such as
206 Miscanthus are already being cofired with coal at powerstations. There is understandable
207 distaste for using food crops such as wheat and maize for fuel, but currently 30% of the US
208 maize crop is used for ethanol production, and sustainable solutions are being
209 found. Sugarcane in Brazil significantly reduces Brazil's imports of fossil fuels. Agave in hot
210 arid regions can provide very high yields (> 30T/ha) of dry matter with low water inputs
211 compared to other crops. For ameliorating global warming, CO₂ must be taken out of the air
212 and not put back. There is considerable interest in "biochar" in which plant material is heated
213 without air to convert the carbon into charcoal. In this form, carbon cannot readily re-enter
214 the air, and if added to the soil, can increase fertility. Carbon markets do not currently
215 provide sufficient incentive for farmers to grow crops simply to take CO₂ out of the air.

216

217 **A7. How do plants contribute to the ecosystem services upon which humanity**
218 **depends?**

219 Ecosystem services are those benefits we human beings derive from nature. They can be
220 loosely divided into supporting (e.g. primary production, soil formation) provisioning (e.g.
221 food, fibre, fuel), regulating (e.g. climate regulation, disease regulation) and cultural (e.g.

222 aesthetic, recreational) services. Plants are largely responsible for primary production and
223 therefore are critical for maintaining human well-being, but they also contribute in many
224 other ways. The Earth receives virtually no external inputs apart from sunlight, and biological
225 and geochemical recycling of matter are essential regenerative processes for life to be
226 sustained. Plants drive much of the recycling of carbon, nitrogen, water, oxygen, and much
227 more. They are the source of virtually all the oxygen in the atmosphere, and they are also
228 responsible for at least half of carbon cycling (hundreds of billions of metric tons per year).
229 The efficiency with which plants take up major nutrients, such as nitrogen and phosphorus,
230 has major impacts on agricultural production, but the application of excess fertilisers causes
231 eutrophication which devastates water ecosystems. Plants are already recognized as important
232 for sustainable development (e.g. plants for clean water) but there are many other ways that
233 plants might contribute. A combined approach of understanding both the services provided
234 by ecosystems and how plants contribute to the functioning of such ecosystems will require
235 interdisciplinary collaboration between plant scientists, biogeochemists, and ecologists.

236

237 **A8. What new scientific approaches will be central to plant biology in the 21st**
238 **Century?**

239 Biologists now have a good general understanding of the principles of cell and developmental
240 biology and genetics, and how plants function, change, and adapt to their environment.
241 Addressing the questions in this list, including generating crops that can deal with future
242 challenges, will require detailed knowledge of many more processes and species. New high
243 throughput technologies for analyzing genomes, phenotypes, protein complements, and the
244 biochemical composition of cells, can provide us with more detailed information in a week

245 than has ever been known before about a particular process, organism or individual. This is
246 delivering a deluge of information that is both exhilarating and daunting. The challenge is to
247 develop robust ways of analyzing and interpreting this mountain of data to answer questions
248 and deliver new insights. The skill sets required to make full use of the new information
249 extend far beyond those previously expected from biologists. There is general agreement that
250 we need a new era of collaboration between all types of plant scientist, geographers,
251 geologists, statisticians, mathematicians, engineers, computer scientists, and other biologists
252 to evaluate complex data, find new relationships, develop and test hypotheses, and make new
253 discoveries. Challenges include understanding complex traits and interactions with the
254 environment, generating ‘designer crops’, and using modelling to predict how different
255 genotypes will cope with alterations in the climate.

256

257 **A9. a. How do we ensure that society appreciates the full importance of plants?**

258 Plants are fundamental to all life on earth. They provide us with food, fuel, fibre, industrial
259 feedstocks, and medicines. They render our atmosphere breathable. They buffer us against
260 extremes of weather and provide food and shelter for much of the life on our planet.
261 However, we take plants and the benefits that they confer for granted. Given their
262 importance, should we not pay plants greater attention and give higher priority to improving
263 our understanding of them? Awareness could be increased through the media, school
264 education, and public understanding of science activities, but a major step change in activity
265 will be required to make a substantial difference.

266 **b. How can we attract the best young minds to plant science so that they can**
267 **address Grand Challenges facing humanity such as climate change, food security,**
268 **and fossil fuel replacement?**

269 Everyone knows that we need doctors, and the idea that our best and brightest should go into
270 medicine is embedded in our culture. But even more important than medical treatment is the
271 ability to survive from day to day; this requires food, shelter, clothes, and energy, all of
272 which depend on plants. Beyond these essentials, plants are the source of many other
273 important products. As is clear from the other questions on this list, plant scientists are
274 tackling many of the most important challenges facing humanity in the 21st century,
275 including climate change, food security, and fossil fuel replacement. Making the best possible
276 progress will require exceptional people. We need to radically change our culture so that
277 "Plant Scientist" (or, if we can rehabilitate the term, "Botanist") can join "Doctor", "Vet" and
278 "Lawyer" in the list of top professions to which our most capable young people aspire.

279

280 **A10. How do we ensure that sound science informs policy decisions?**

281 It is important that policy decisions that can affect us all, for example environmental
282 protection legislation, are based on robust and objective evidence underpinned by sound
283 science. Without this, the risk of unintended consequences is severe. Ongoing dialogue
284 between policy makers and scientists is therefore critical. How do we initiate and sustain this
285 dialogue? How do we ensure that policy makers and scientists are able to communicate
286 effectively? What new mechanisms are needed to enable scientists to respond to the needs of
287 policy makers and *vice versa*?

288

289 The Supporting Information in the online version of this paper provides explanatory text for
290 the remaining questions.

291 **A11. How can we translate our knowledge of plant science into food security?**

292 **A12. Which plants have the greatest potential for use as biofuels with the least affects on**
293 **biodiversity, carbon footprints and food security?**

294 **A13. Can crop production move away from being dependent on oil-based technologies?**

295 **A14. How can we use plant science to prevent malnutrition?**

296 **A15. How can we use knowledge of plants and their properties to improve human**
297 **health?**

298 **A16. How do plants and plant communities (morphology, colour, fragrance, sound,**
299 **taste etc.) affect human well being?**

300 **A17. How can we use plants and plant science to improve the urban environment?**

301 **A18. How do we encourage and enable the interdisciplinarity that is necessary to**
302 **achieve the UN's Millennium Development Goals that address poverty and the**
303 **environment?**

304

305 **B. Environment and Adaptation**

306 Plants have evolved to cope with changes in their environment but their adaptability has not
307 necessarily been preserved as crops have been selected. Assessing and utilizing the capacity
308 of plants to adapt should help to increase the use of more marginal land for cultivation, and
309 increase agricultural production despite changes in climate.

310

311 **B1. How can we test if a trait is adaptive?**

312 **B2. What is the role of epigenetic processes in modulating response to the environment**
313 **during the life span of an individual?**

314 **B3. Are there untapped potential benefits to developing perennial forms of currently**
315 **annual crops?**

316 **B4. Can we generate a step change in C3 crop yield through incorporation of a C4 or**
317 **intermediate C3/C4 or CAM mechanism?**

318 **B5. How do plants regulate the proportions of storage reserves laid down in various**
319 **plant parts?**

320 **B6. What is the theoretical limit of productivity of crops and what are the major factors**
321 **preventing this being realized?**

322 **B7. What determines seed longevity and dormancy?**

323 **B8. How can we control flowering time?**

324 **B9. How does signalling and cross talk between the different plant hormones operate?**

325 **B10. Can we develop salt/heavy metal/drought tolerant crops without creating invasive**
326 **plants?**

327 **B11. Can plants be better utilised for large-scale remediation and reclamation efforts on**
328 **degraded and/or toxic lands?**

329 **B12. How can we translate/exploit our knowledge of plants and ecosystems into “clever**
330 **farming” practices?**

331 **B13. Can alternatives to monoculture be found without compromising yields?**

332 **B14. Can plants be bred to overcome dry land salinity or even reverse it?**

333 **B15. Can we develop crops that are more resilient to climate fluctuation without yield**
334 **loss?**

335 **B16. Can we understand (explain and predict) the succession of plant species in any**
336 **habitat, and crop varieties in any location, under climate change?**

337 **B17. To what extent are the stress responses of cultivated plants appropriate for current**
338 **and future environments?**

339 **B18. Are endogenous plant adaption mechanisms enough to keep up with the pace of**
340 **man-made environmental change?**

341 **B19. How can we improve our cultivated plants to make better use of finite resources?**

342 **B20. How do we grow plants in marginal environments without encouraging**
343 **invasiveness?**

344 **B21. How can we use the growing of crops to limit deserts spreading?**

345

346

347 **C. Species Interactions**

348 Cultivated plants interact directly with other species, including pathogens, pests, symbionts
349 and weeds. Some interactions are beneficial, whereas others can cause devastating
350 agricultural losses. It remains a challenge to control deleterious species without causing
351 significant environmental damage, and there is untapped potential in interactions with
352 beneficial species.

353

354 **C1. What are the best ways to control invasive species including plants, pests and**
355 **pathogens?**

356 **C2. Can we provide a solution to intractable plant pest problems in order to meet**
357 **increasingly stringent pesticide restrictions?**

358 **C3. Is it desirable to eliminate all pests and diseases in cultivated plants?**

359 **C4. What is the most sustainable way to control weeds?**

360 **C5. How can we simultaneously eradicate hunger and conserve biodiversity?**

361 **C6. How can we move nitrogen-fixing symbioses into non-legumes?**

362 **C7. Why is symbiotic nitrogen fixation restricted to relatively few plant species?**

363 **C8. How can the association of plants and mycorrhizal fungi be improved or extended**
364 **toward better plant and ecosystem health?**

365 **C9. How do plants communicate with each other?**

366 **C10. How can we use our knowledge of the molecular biology of disease resistance to**
367 **develop novel approaches to disease control?**

368 **C11. What are the mechanisms for systemic acquired resistance to pathogens?**

369 **C12. When a plant resists a pathogen, what stops the pathogen growing?**

370 **C13. How do pathogens overcome plant disease resistance, and is it inevitable?**

371 **C14. What are the molecular mechanisms for uptake and transport of nutrients?**

372 **C15. Can we use non-host resistance to deliver more durable resistance in plants?**

373

374

375 **D. Understanding and Utilizing Plant Cells**

376 Plant structure and function depend on the composition and behavior of plant cells. A lot of
377 progress has been made towards identifying cellular components (including DNA, RNA,
378 proteins, cell wall components, membranes) and understanding how they contribute to
379 specific processes (such as development, metabolism, and pathogen-resistance). The early
380 questions in this section address frontiers in our understanding of plant cells, and potentially
381 timely applications are tackled later.

382

383 **D1. How do plant cells maintain totipotency and how can we use this knowledge to**
384 **improve tissue culture and regeneration?**

385 **D2. How is growth and division of individual cells co-ordinated to form genetically**
386 **programmed structures with specific shapes, sizes and compositions?**

387 **D3. How do different genomes in the plant talk to one another to maintain the**
388 **appropriate complement of organelles?**

- 389 **D4. How and why did multicellularity evolve in plants?**
- 390 **D5. How can we improve our understanding of programmed developmental gene**
391 **regulation from a genome sequence?**
- 392 **D6. How do plants integrate multiple environmental signals and respond?**
- 393 **D7. How do plants store information on past environmental and developmental events?**
- 394 **D8. To what extent do epigenetic changes affect heritable characteristics of plants?**
- 395 **D9. Why are there millions of short RNAs in plants and what do they do?**
- 396 **D10. What is the array of plant protein structures?**
- 397 **D11. How do plant cells detect their location in the organism and develop accordingly?**
- 398 **D12. How do plant cells restrict signalling and response to specific regions of the cell?**
- 399 **D13. Is there a cell wall integrity surveillance system in plants?**
- 400 **D14. How are plant cell walls assembled, and how is their strength and composition**
401 **determined?**
- 402 **D15. Can we usefully implant new synthetic biological modules in plants?**
- 403 **D16. To what extent can plant biology become predictive?**
- 404 **D17. What is the molecular / biochemical basis of heterosis?**
- 405 **D18. How do we achieve high frequency targeted homologous recombination in plants?**
- 406 **D19. What factors control the frequency and distribution of genetic crossovers during**
407 **meiosis?**

408 **D20. How can we use our knowledge about photosynthesis and its optimization to better**
409 **harness the energy of the sun?**

410 **D21. Can we improve algae to better capture CO₂ and produce higher yields of oil or**
411 **hydrogen for fuel?**

412 **D22. How can we use our knowledge of carbon fixation at the biochemical, physiological**
413 **and ecological levels to address the rising levels of atmospheric carbon dioxide?**

414 **D23. What is the function of the phenomenal breadth of secondary metabolites?**

415 **D24. How can we use plants as the chemical factories of the future?**

416 **D25. How do we translate our knowledge of plant cell walls to produce food, fuel and**
417 **fibre more efficiently and sustainably?**

418

419

420 **E. Diversity**

421 Current estimates are of at least a quarter of a million flowering plants in the world, the vast
422 majority of which have not been tested for useful properties. Questions in this section address
423 the need to identify plants with potential for human benefit that has yet to be recognized, and
424 to do so in a sustainable and responsible manner. The resulting knowledge and natural
425 resources could then be used to tackle new challenges as they arise.

426

427 **E1. How much do we know about plant diversity?**

- 428 **E2. How can we better exploit a more complete understanding of plant diversity?**
- 429 **E3. Can we increase crop productivity without harming biodiversity?**
- 430 **E4. Can we define objective criteria to determine when and where intensive or extensive**
431 **farming practices are appropriate?**
- 432 **E5. How do plants contribute to ecosystem services?**
- 433 **E6. How can we ensure the long-term availability of genetic diversity within socio-**
434 **economically valuable gene pools?**
- 435 **E7. How do specific genetic differences result in the diverse phenotypes of different**
436 **plant species?- i.e. why is an oak tree an oak tree and a wheat plant a wheat plant?**
- 437 **E8. Which genomes should we sequence and how can we best extract meaning from the**
438 **sequences?**
- 439 **E9. What is the significance of variation in genome size?**
- 440 **E10. What is the molecular and cellular basis of plants' longevity and can plant life**
441 **spans be manipulated?**
- 442 **E11. Why is the range of lifespans in the plant kingdom so much greater than in**
443 **animals?**
- 444 **E12. What is a plant species?**
- 445 **E13. Why are some clades of plants more species rich than others?**
- 446 **E14. What is the answer to Darwin's "abominable mystery" of the rapid rise and**
447 **diversification of angiosperms?**

448 **E15. How has polyploidy contributed to the evolutionary success of flowering plants?**

449 **E16. What are the closest fossil relatives of the flowering plants?**

450 **E17. How do we best conserve phylogenetic diversity in order to maintain evolutionary**
451 **potential?**

452

453

454 **Conclusions**

455 Plant science is central to addressing many of the most important questions facing humanity.
456 Secure food production and quality remain key issues for the world in the 21st Century, and
457 the importance of plants extends well beyond agriculture and horticulture as we face
458 declining fossil fuel reserves, climate change, and a need for more sustainable methods to
459 produce fuel, fibre, wood, and industrial feedstocks. There is also untapped potential in
460 optimising the nutritional properties of foods, and in identifying novel plant products such as
461 medicines. Tackling these frontiers will require new scientific methods and collaborations as
462 existing approaches are delivering incomplete answers.

463

464 Many of the most important questions that we have identified can only be addressed by the
465 integrated efforts of scientists with diverse expertise. For example, many require integration
466 between scientists working to improve crops and those working on environmental stability
467 and ecosystem services. Funding mechanisms, scientific publishing and conferences could be
468 more effective in supporting and encouraging the efficient transfer of knowledge between

469 different areas of plant science and this should be addressed. In the longer term, changes to
470 higher education may be required to ensure that future researchers have the most suitable
471 background knowledge and skill sets to address the research challenges that they are likely to
472 face.

473

474 As plant science becomes increasingly important, we need to attract the brightest and best to
475 careers in plant research. School education does not include the most interesting or relevant
476 aspects of plant science, and discourages young people from studying the subject at
477 University. This is indefensible in a world with such a strong requirement for outstanding
478 plant scientists, and steps should be taken to put it right.

479

480 Research moves quickly, and our questions and suggestions about the ways that they might
481 be tackled, will require revision, but in the meantime we hope that they will stimulate
482 discussion, and encourage plant scientists to think beyond the limits of their own specific
483 fields about the most important research that can conceivably be done, the most promising
484 approaches that can be developed and applied, and the most significant discoveries that can
485 possibly be made.

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496 **Supporting Information**

497 Notes containing explanatory text for questions A11. – E17.