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Microbial symbionts: a potential bio-boom

Abstract

The large and rapidly growing human population and climatic changes are challenges for world food security. For human food security, a significant increase in crop production is needed to avoid humanitarian crises in the future. In modern history, significant increases in crop production have been achieved via agrochemicals, classical breeding and genetically modified crops. However, based on progress achieved by these methods, further significant increases in crop production will require both current and novel multi disciplinary approaches. Microbial symbionts have great potential to help increase crop production to meet future demand. Microbial symbionts in crop production are a safe and sustainable technology that will be heavily incorporated in future agricultural systems. This review highlights briefly the role of various methods used to improve crop productivity and the possible role of microorganisms in agriculture.

Keywords: microbial symbionts, agrochemicals, breeding, genetically modified crops, sustainable agriculture

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Abbreviations: NSF, national science foundation; IAA, indole-3-acetic acid

Introduction

Although progress in hunger reduction has been made at the global level the ultimate challenge to be conquered is food insecurity. Increases in the quality and quantity of food produced will be required to meet the increased demands of a growing population.[1] Global trends suggest that hunger reduction still masks disparities in food security that exist within and among populations. Globally as of 2009, 1.02billion people suffer from chronic hunger and one in seven people have an insufficient food supply to live an active, healthy life.[2] Continuing population and consumption growth will further increase the global demand for food. By 2050, the world population is expected to increase by 2.3billion to reach a total of 9.1billion and further exacerbate the international challenge of food insecurity.[2] Such population growth will necessitate the daunting task of increasing overall food production by 70–100%.[3–5] If such a food production target proves to be unattainable, human populations in some areas of the world will face unavoidable starvation. Starvation is a humanitarian crisis with far-reaching effects. Hungry individuals are more likely to have clinical levels of anxiety and aggression, resulting in an angry population.[6] Ongoing global climate change resulting in flooding, drought and heat waves will also significantly increase the difficulty of reaching the goal of nearly doubling crop production. At the same time food producers are experiencing increased competition for land, water, energy and other resources devoted solely to agriculture.[7,8]

During the Green Revolution, farmers relied heavily on various agrochemicals (currently a $180billion market) to protect crops against plant pathogens and to increase production on nutrient-depleted soils. These practices showed remarkable success in increasing crop production worldwide and helped evade famine in many countries, while only requiring a 9-12% increase in crop area.[9] Unfortunately, this Green Revolution based partially on agrochemicals was not sustainable and will not adequately address future food production needs. In addition, agrochemicals are expensive and can negatively influence the environment.[10–13] For example agrochemicals have leaked into and polluted water sources and destroyed beneficial insects and microorganisms that are naturally present, making crops more susceptible to disease. Overall, the use of agrochemicals is still valuable under certain conditions and will no doubt continue. However, we must find safer and more sustainable alternatives to prevent and control agricultural pests and improve soil viability. For hundreds of year's conventional plant breeding has allowed for the development of new varieties of crops via various selection methods, pure line hybrid technology and mutation breeding. Breeding programs have also contributed to the production of quality crops with higher nutritional values.[14] Conventional breeding has increased corn yield for decades.[15] However yield improvement gains due to breeding have leveled off or decreased in recent years for most staple crops,[16,17] demonstrating that conventional plant breeding alone will no longer sustain future global demand.

Engineering crops continues to improve yields and other important crop traits. Genetic modification of crops has increased herbicide tolerance, improved resistance to insects and environmental stress and generated valuable traits such as nutrient-enhanced seeds (such as Golden Rice with vitamin A).[18–20] However these methods are relatively slow, expensive and applicable only to the most important crop species. Moreover, in many countries grower access to genetically modified crops is restricted because of bioethical and political concerns.[21] Fifteen years after the introduction of the first genetically modified crops in the US, many farmers continue to raise concerns regarding the economic and environmental impacts, the evolution of resistant weeds and consumer acceptance of genetically modified crops.[22] Additionally progress in the development of cultivars that can efficiently tolerate drought and heat waves while maintaining yield stability has been extremely slow. To date, Monsanto has developed the only commercial drought-tolerant maize (DroughtGard) through bacterial gene transfer. According to Monsanto, DroughtGard has an average yield advantage of 5 bushels per acre over competitor products when tested by 250 growers across the western Great Plains. Areport from Union of Concerned Scientists[23] claims that Drought

Gard reduces crop losses only during moderate droughts and contends that it does not differ from other corn varieties interms of water use efficiency. However genetic engineering has significantly increased the quantity and quality of some crops; therefore, it has been proven beneficial for use in attaining the needed 70–100% increase in crop production. Following the predominant use of agrochemicals and conventional breeding during the Green Revolution andbillions of dollars spent on biotechnological approaches, the results show only a slight increase followed by a plateau in crop production.[24] The path to sustainable agriculture will not be based solely on the current, proven effectiveness of agrochemicals, breeding and genetically modified crops, but rather on devising new sustainable approaches to add to the improvements made possible by these methods, in hopes of reaching the targeted production increase. A sustainable agricultural system will require an interdisciplinary approach that integrates current and new technologies. Additionally, the new approach should not only focus on improving crop yields and mitigating the effects of climate change but must also consider other important ecological factors.

The application of symbiotic microorganisms in sustainable agriculture has immense potential for increasing crop yields and mitigating climate change with minimal disturbance to the environment.[25–27] Microbial preparations will not only reduce the use of agrochemicals and improve the performance of crop varieties developed via breeding and genetic modification, but will also help in cycling nutrients and building soil structure. The use of a microbial symbiont with the reintroduction of multiple cropping systems has the potential to preserve and restore the natural microorganism populations present in agricultural lands. The use of symbiotic microorganisms is a novel approach that can inspire a new “Bio-Boom” similar to the Green Revolution of the past century. Endophytic bacteria and fungi are ubiquitous and ancient symbionts of almost all plant species, dating back over 400million years,[28,29] with a large influence on plant physiology. Their existence within plant tissues increases nutrient uptake efficiency, protects host plants against diseases as well as herbivorous and abiotic stresses and promotes the growth of foliage and deeper root systems.[30–32] In the past the vast majority of plant productivity and physiology research has focused on plants as individuals. However plants constitute an ecosystem that harbors many other microorganisms including endophytic symbionts. Fortunately, many researchers are now focusing on the various microbiomes associated with wild and crop plants. High-throughput DNA sequencing, metagenomics, transcriptomics, proteomics and metabolomics approaches offer significant advancements in knowledge gained from examining plant microbiomes and their potential roles in sustainable plant productivity.[33,34] For example in-depth 454 sequencing has been used to reveal fungal endophyte communities in bur oak, mangrove and beech treestands,[35–37] and metabolomic analyses have identified the roles that endophytic secondary metabolites play in their host plants.[38,39]

Researchers are working on the discovery of new bacterial and fungal symbionts that improve crop productivity and other traits and are trying to understand the molecular mechanisms that govern the symbiotic relationship between plants and their symbionts. Many researchers have reported the discovery of microbial symbionts from wild and crop plants. Several of these symbionts show positive effects on crop productivity and stress tolerance of tomato, wheat, rice, barley, and other crops mainly under green house conditions.[40–43] Microbial symbionts can increase plant productivity and stress tolerance *via* various mechanisms. For example, bacterial symbionts also known as plant growth-promoting rhizobacteria, can enhance plant growth via a variety of mechanisms such as improved nutrient solubilization and uptake,[44] nitrogen fixation,[45,46] production of volatile organic compounds[47] and modification of plant hormonal status.[48,49] Fungal symbionts can also improve plant productivity by various mechanisms including increased plant water-use efficiency maximized photosynthetic rate or increased production of metabolites such as the sugar trehalose or growth hormones such as gibberellins and auxin indole-3-acetic acid (IAA).[31,43,50–53] In addition fungal symbionts can regulate a diverse set of plant genes. For example *Arabidopsis thaliana* colonized by *Piriformospora indica* showed faster and greater up-regulation of nine drought stress-related genes[54] and in *Theobroma cacao* colonized with *Trichoderma hamatum* the endophyte altered expression of 19 drought-responsive genes and promoted greater seedling growth when plants were exposed to drought.[55] Over the last few years, public and private sector researchers have been racing to discover new beneficial soil microbes to improve crop production. Companies historically interested in breeding and biotechnology approaches are now investing in microbial products to promote sustainable microbial agricultural systems. Many other smaller agriculture-based companies have produced and sold microbial-based products that improve various aspects of crop production. In 2012 more than $ 2billion in agricultural microbe products were sold worldwide and sales are expected to grow by roughly 15% each year.[56] However this is a small fraction of agricultural expenditures compared to the $ 180 and $ 15.6billion spent on agrochemicals and biotechnology crops respectively.[57]

Conclusion

The use of microbial symbiontsto increase crop productivity and stress tolerance is an essential step towards the new green revolution, the Bio-Boom. The Bio-Boom will significantly contribute to the development of friendly and sustainable agricultural systems that benefit both small and large farm producers due to their relatively low costs. In addition, the Bio-Boom will help bridge the gap between food production and the ever-growing human population. However one should note that the effectiveness of microbial symbionts vary by crop and habitat. Also careful consideration should be taken before introducing foreign symbionts into a new habitat. The use of habitat-specific microbial symbionts is key for a safe and successful Bio-Boom.

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Conflict of interest

Author declares that there is no conflict of interest.

References

1. The State of Food Insecurity in the World, Economic crises – impacts and lessons learned. Rome: Food and Agriculture Organization of the United Nations, *Food and Agriculture Organization (FAO)*. 2009.
2. The State of Food and Agriculture. Rome: Food and Agriculture Organization of the United Nations. *Food and Agriculture Organization (FAO)*. 2009.
3. Food and Agriculture Organization (FAO). *Declaration of the World Summit on Food Security*. Rome: Food and Agriculture Organization of the United Nations; 2009. p. 16–18.
4. World Bank (WB). *World Development Report Agriculture for Development*. Washington: World Bank; 2008.

5. Royal Society (RS). *Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture.* London: Royal Society; 2009.

6. Kleinman RE, Murphy JM, Little M, et al. Hunger in children in the United States: potential behavioral and emotional correlates. *Pediatrics*. 1998;101(1):E3.

7. Foley JA, Raman KN, Brauman KA, et al. Solutions for a cultivated planet. *Nature*. 2011;478(7369):337–342.

8. Lambin EF, Meyfroidt P. Global land use change, economic globalization, and the looming land scarcity. *Proc Natl Acad Sci USA*. 2011;108(9):3465–3472.

9. Pretty J. Agricultural sustainability: concepts, principles and evidence. *Philos Trans R Soc Lond B Biol Sci*. 2008;363(1491):447–465.

10. Bueno CS, Ladha JK. Comparison of soil properties between continuously cultivated and adjacent uncultivated soils in rice-based systems. *Biology and Fertility of soils*. 2009;45(5):499–509.

11. Fox JE, Gulledge J, Engelhaupt E, et al. Pesticides reduce symbiotic efficiency of nitrogen-fixing rhizobia and host plants. *Proc Natl Acad Sci USA*. 20104(24):10282–10287.

12. Desneux N, Decourtye A, Delpuech JM. The sublethal effects of pesticides on beneficial arthropods. *Annu Rev Entomol*. 2007;52:81–106.

13. Scoones I. The politics of global assessments: the case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). *Journal of Peasant Studies*. 2009;36(3):547–571.

14. Bhullar NK, Gruissem W. Nutritional enhancement of rice for human health: the contribution of biotechnology. *Biotechnol Adv*. 2013;31(1):50–57.

15. Duvick DN. The Contribution of Breeding to Yield Advances in maize (*Zea mays L.*). *Advances in Agronomy*. 2005;86:83–145.

16. Fischer RA, Edmeades GO. Breeding and cereal yield progress. *Crop Science*. 2010;50(Suppl1):85–98.

17. Graybosch RA, Peterson CJ. Genetic improvement in winter wheat yields in the Great Plains of North America, 1959-2008. *Crop Science*. 2010;50(5):1882–1890.

18. Mayer JE, Pfeiffer WH, Beyer P. Biofortified crops to alleviate micronutrient malnutrition. *Curr Opin Plant Biol*. 2008;11(2):166–170.

19. Duc G, Hesham A, Shiying B, et al. Breeding Annual Grain Legumes for Sustainable Agriculture: New Methods to Approach Complex Traits and Target New Cultivar Ideotypes. *Critical Reviews in Plant Sciences*. 2015;34(1–3):381–411.

20. Vaz Patto MC, Amarowicz R, Alberta Aryee NA, et al. Achievements and challenges in improving the nutritional quality of food legumes. *Critical Reviews in Plant Sciences*. 2015;34(1–3):105–143.

21. Tester M, Langridge P. Breeding technologies to increase crop production in a changing world. *Science*. 2010;327(5967):818–822.

22. Fernandez-Cornejo J, Wechsler S, Mike L, et al. Genetically Engineered Crops in the United States. *US Department of Agriculture, Economic Research Service; ERR–162*. 2014.

23. Gurian Sherman D. *High and dry: Why genetic engineering is not solving agriculture's drought problem in a thirsty world.* USA: Union of Concerned Scientists; 2012.

24. Alston JM, Beddow JM, Pardey PG. Agriculture. Agricultural research, productivity and food prices in the long run. *Science*. 2009;325(5945):1209–1210.

25. Barrow JR, Lucero ME, Reyes VI, et al. Do symbiotic microbes have a role in plant evolution, performance and response to stress? *Commun Integr Biol*. 2008;1(1):69–73.

26. Rodriguez RJ, Henson J, Volkenburgh VE, et al. Stress tolerance in plants via habitat-adapted symbiosis. *ISME J*. 2008;2(4):404–416.

27. Dubey A, Lal R. Carbon footprint and sustainability of agricultural production systems in Punjab, India, and Ohio, USA. *Journal of Crop Improvement*. 2009;23(4):332–350.

28. Krings M, Taylor TN, Hass H, et al. Fungal endophytes in a 400-million-yr-old land plant: infection pathways, spatial distribution, and host responses. *New Phytol*. 2007;174(3):648–657.

29. Rodriguez JR, White JF, Arnold AE, et al. Fungal endophytes: diversity and functional roles. *New Phytol*. 2009;182(2):314–330.

30. Lee K, Pan JJ, May G. Endophytic Fusarium verticillioides reduces disease severity caused by Ustilago maydis on maize. *FEMS Microbiol Lett*. 2009;299(1):31–37.

31. Herre EA, van Bael SA, Maynard Z, et al. *Tropical plants as chimera: some implications of foliar endophytic fungi for the study of host plant defense, physiology, and genetics.* New York: Cambridge University Press; 2005. p. 226–240.

32. Arnold AE, Engelbrecht BMJ. Fungal endophytes nearly double minimum leaf conductance in seedlings of a neotropical tree species. *Journal of Tropical Ecology*. 2007;23(3):369–372.

33. Committee on Metagenomics: Challenges and Functional Applications, National Research Council. *The New Science of Metagenomics: Revealing the Secrets of Our Microbial Planet*. National Academy of Sciences, Washington; 2007.

34. Guttman DS, McHardy AC, Lefert PS. Microbial genome-enabled insights into plant-microorganism interactions. *Nat Rev Genet*. 2014;15(12):797–813.

35. Jumpponen A, Jones K. Massively parallel 454 sequencing indicates hyperdiverse fungal communities in temperate Quercus macrocarpa phyllosphere. *New Phytol*. 2009;184(2):438–448.

36. Coince A, Cordier T, Lengelle J, et al. Leaf and root-associated fungal assemblages do not follow similar elevational diversity patterns. *PloS One*. 2014;9(6):e100668.

37. Arfi Y, Buee M, Marchand C, et al. Multiple markers Pyrosequencing reveals highly diverse and host-specific fungal communities on the mangrove trees Avicennia marina and Rhizophora stylosa. *FEMS Microbiol Ecol*. 2012;79(2):433–444.

38. Aly AH, Debbab A, Proksch P. Fungal endophytes: unique plant inhabitants with great promises. *Appl Microbiol Biotechnol*. 2011;90(6):1829–1845.

39. Brader G, Compant S, Mitter B, et al. Metabolic potential of endophytic bacteria. *Curr Opin Biotechnol*. 2014;27:30–37.

40. Waller F, Achatz B, Baltruschat H, et al. The endophytic fungus Piriformospora indica reprograms barley to salt-stress tolerance, disease resistance, and higher yield. *Proc Natl Acad Sci USA*. 2005;102(38):13386–13391.

41. Mahmoud RS, Narisawa K. A new fungal endophyte, Scolecobasidium humicola, promotes tomato growth under organic nitrogen conditions. *PloS One*. 2013;8(11):e78746.

42. Hubbard M, Germida JJ, Vujanovic V. Fungal endophytes enhance wheat heat and drought tolerance in terms of grain yield and second-generation seed viability. *J Appl Microbiol*. 2014;116(1):109–122.

43. Khan AL, Muhammad W, Javid H, et al. Endophytes *Aspergillus caespitosus* LK12 and *Phoma* sp. LK13 of *Moringa peregrina* produce gibberellins and improve rice plant growth. *Journal of Plant Interactions*. 2014;9(1):731–737.

44. Sharma A, Shankhdhar D, Shankhdhar SC. Enhancing grain iron content of rice by the application of plant growth promoting rhizobacteria. *Plant Soil Environment*. 2013;59(2):89–94.

45. Setten L, Soto G, Mozzicafreddo M, et al. Engineering pseudomonas protegens Pf-5 for nitrogen fixation and its application to improve plant growth under nitrogen-deficient conditions. *PloS One*. 2013;8(5):e63666.

46. Boddey RM, Dobereiner J. Nitrogen fixation associated with grasses and cereals: recent progress and perspectives for the future. *Fertilizer Research.* 1995;42(1–3):241–250.

47. Ryu CM, Farag MA, Hu CH, et al. Bacterial volatiles promote growth in Arabidopsis. *Proc Natl Acad Sci USA*. 2003;100(8):4927–4932.

48. Talboys PJ, Owen DW, Healey JR, et al. Auxin secretion by Bacillus amyloliquefaciens FZB42 both stimulates root exudation and limits phosphorus uptake in Triticum aestivium. *BMC Plant Biol*. 2014;14:51.

49. Borriss R. Bacillus A Plant-Beneficial Bacterium. *Principles of Plant-Microbe Interactions*. 2015:379–391.

50. Marquez LM, Redman RS, Rodriguez RJ, et al. A virus in a fungus in a plant: three-way symbiosis required for thermal tolerance. *Science.* 2007;315(5811):513–515.

51. Redman RS, Sheehan KB, Stout RG, et al. Thermotolerance generated by plant/fungal symbiosis. *Science*. 2002;298(5598):1581.

52. Morsy MR, Oswald J, He J, et al. Teasing apart a three-way symbiosis: Transcriptome analyses of Curvularia protuberata in response to viral infection and heat stress. *Biochem Biophys Res Commun*. 2010;401(2):225–230.

53. Contreras Cornejo HA, Macias RL, Alfaro CR, et al. Trichoderma spp. Improve Growth of Arabidopsis Seedlings Under Salt Stress through Enhanced Root Development, Osmolite Production, and Na+ Elimination Through Root Exudates. *Mol Plant Microbe Interact.* 2014;27(6):503–514.

54. Sherameti, I, Tripathi S, Varma A, et al. The root-colonizing endophyte Pirifomospora indica confers drought tolerance in Arabidopsis by stimulating the expression of drought stress-related genes in leaves. *Mol Plant Microbe Interact.* 2008;21(6):799–807.

55. Bae H, Sicher RC, Kim MS, et al. The beneficial endophyte Trichoderma hamatum isolate DIS 219b promotes growth and delays the onset of the drought response in Theobroma cacao. *J Exp Bot*. 2009;60(11):3279–3295.

56. Novozymes. *The Novozymes Report is an integrated financial, environmental, and social annual report*. 2013.

57. James C. *Global status of commercialized biotech/GM crops: 2010.* International Service for the Acquisition of Agri-biotech Applications (ISAAA), USA; 2010.