The DNA-®*evolution* of Agriculture

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March 2015

Abstract

By 2050, world food, feed, and biofuels requirements will more than double as a result of population growth, dramatically changing consumption patterns, food losses, food waste and increasing demand for pet food. This means, we will have to produce more crops worldwide during this period than over the last 10,000 years put together.

But, several studies have shown that yield trends of global key or food security crops are insufficient to double global crop production by 2050. Nevertheless, yields of crops and productivity of agriculture must be increased to boost production in order to meet global rising demands.

To close the gap, there is a need for a second green ***®evolution*** – a green **DNA-®*evolution* in agriculture**. The green branch of DNA will pollinate agriculture by using functional genomics, marker-assisted selection, genomics-assisted breeding, genetic engineering, genome engineering, synthetic biology, and digital cells in order to improve plants of the future in time. Key breeding goals are determined and prioritized to solve actual and future challenges. Top priority is given to crop functional genomics and the impact of different soils (Factor S^n) as well as water availabilities (Factor W^n) especially in greenhouses and fields.

Farmers, scientists, politicians, the public at large, and young people especially should be encouraged to be optimistic and to go for and improve the **DNA-®*evolution*** of agriculture in order to add value to agriculture, to societies and to enable a peaceful life on earth.

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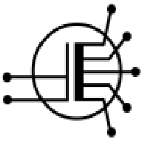
Analysis



Symbol for
Synthetic Biology

> **"Agriculture, the mother of all sciences has always been, and continues to be, one of the ways in which humankind has improved the basis of human existence on earth. A world without agriculture and agriculture without DNA is a paradox. The DNA is the key source for crop development, breeding, biotechnology, genomics, genome engineering, synthetic biology, and last but not least for bio-sustainability of humankind."**
>
> ***M. Kern, 2014***

Genetics – modifying the building blocks of life, **R**obotics – building autonomous machines to do our bidding, **A**rtificial **I**ntelligence – machines that learn, **N**anotechnology – building things atom by atom. Taken together, these form the acronym **G-R-A-I-N** (*Mulhall, 2002*). This megamerger of super sciences may transform who and what we are.

Very soon, genome maps will be completed of all organisms of interest, and the translation, i.e. finding and using key functions of relevant genes, is proceeding at a rapid pace. From more than 300 000 known land plants, more than 100 plant genomes (*Mittler and Shulaev, 2013*) including wheat (*Science, 7/2014*) have been published to date; 1,000 will be documented within the next couple of years. An actual overview of the first 50 plant genomes is given by *Todd and Jackson* (*2013*).

The green branch of DNA will pollinate agriculture by using functional genomics, marker-assisted selection, genomics-assisted breeding, genetic engineering, genome engineering, synthetic biology, and digital cells in order to improve plants of the future in time.

New genomic knowledge will make plant breeding very much easier, shorter and better. Genomic research lays the foundations for a greener ***®evolution*** in agriculture and will boost plant breeding to a severe higher cultural level.

At the end of 2014, *Poltronieri and Hong* (*11/2014*) edited an excellent book titled: *"Applied Plant Genomics and Biotechnology"* covering recent advances in the post-genomic era, discussing how different varieties respond to abiotic and biotic stresses, investigating epigenetic modifications and epigenetic memory through analysis of DNA methylation states, applicative uses of RNA silencing and RNA interference in plant physiology and in experimental transgenics, and plants modified to produce high-value pharmaceutical proteins. The book provides an overview on the ongoing activities in the field of applied biotechnology, discusses the future developments in plant functional genomics and explores the new technologies supporting the genetic improvements of plants.

The quality and traits of seed genotypes are key prerequisites for crop yield and quality. Consequently, it is essential to do the right improvement in the right way. Key breeding goals have to be determined and prioritized in order to solve actual and future challenges.

Some goals sowing the seeds for the ideal crop are given modified after *Pennesi*, *2010*:

- **Improving the nutrient content of seeds and edible plant parts.** Vitamin A fortification is already here; soybeans with omega-3 fatty acids are on the way. More vitamins, specific amino acids, minerals, improved fatty acid spectrum, specific enzymes and higher protein content are other goals. For biofuels, the right mix of plant cell-wall components is needed to ease processing.
- **Feed crops with reduced toxins and anti-nutritive factors.** A combination of genetic engineering and conventional breeding may be expected to lead to a reduction of anti-nutritive factors such as protease inhibitors, tannins, phytohaemoglutinins, cyanogens, glucosinates, sanapine (Brassica group), gossypol (cotton) and anti-nutritive oligosaccharides (soybean) in feed crops.
- **No more sex.** Hybrid seeds often produce more vigorous plants, but the seeds of those hybrids are often inferior. Farmers can't always afford to buy new hybrid seeds. One proposed solution is to get hybrids to reproduce asexually through a process called apomixis. Apomixis in rice, for example, could save small farmers $US 4 billion a year.
- **Installing warning lights.** A pigment gene that turns on in times of stress could cause a crop's leaves or stems to change color, and alert farmers to take remedial action. Some think that sensors installed in soils or the air could also do this job.
- **More crop per drop.** Restructuring of root and leaf architecture, and upgrading of drought-response biochemical pathways could increase water-use efficiency. Shallower roots, for instance, can better tap soil-surface moisture.
- **Improving nitrogen efficiency.** Fertilizers are costly for farmers and the environment. Improving a plant's uptake and use would be a big help. Better yet, build into the plant the genes necessary to carry out nitrogen fixation, a job that may one day fall on artificial chromosomes.
- **Improving phosphorous uptake.** This will boost crop yields by triggering more roots, resulting in higher phosphorus uptake.
- **Utilization of phosphite.** Crops are enabled to use phosphite. The effectiveness of such systems in control of weeds and fertilization suggests that this crop system would reduce production costs and energy consumption by replacing separate application of fertilizer and herbicides with a single treatment.
- **Tougher pest defenses.** Adding genes for toxins that kill only pest insects or nematodes can help, as can the addition of genes that attract the enemies of these pests.
- **Resilience against abiotic stress factors.** Drought and salt tolerant crops are on the way.
- **Longer shelf life.** Enhanced control of ripening and senescence could reduce the amount of spoiled harvest.
- **Improving CO_2 assimilation – improving the "Green Power House" of crops**. Re-engineering of the rubisco enzyme system, which uses carbon dioxide from the air and, by means of photosynthesis, con-

verts the energy from sunlight into the sugars that are the building blocks of life. This method will enhance crop yield potentials, increase biomass production in crops, especially in bioenergy crops/trees, and contribute to a more efficient carbon sequestration.

- **Improving the crop plan or crop structure.** For example, roots, stem stability, leaves, infructescenses, fruits and seeds.
- ***De novo* design of crops.** Synthetic biology has the potential for *de novo* design of crops for the future.
- **Multipurpose crops.** Increasing the flexibility of key crops used as food, feed, fiber or fuel.
- **Transformation of crop production** for health care, pharmaceuticals from plants, transformation of the production of pharmaceuticals, plant-made pharmaceuticals, plant bio-pharming, and pharma-farming (*Kern, 2006; Kern, 2007*).
- **Insertion of animal- or human-based genes in plants** in order to overcome allergic reactions.

Furthermore, in addition to the listed breeding targets, top priority should be given to crop functional genomics and the impact of different soils (**Factor S^n**) and water availabilities (**Factor W^n**) especially in greenhouses and fields.

- **Factor S^n ("SSSS SSSS SSSS SSSS WSSL"):** **S**ecrets, **S**and, **S**alt, **S**ilt, **S**cree, **S**ediment, **S**lime, **S**oil, **S**earch, **S**cience, **S**agacity, **S**anity, **S**eeds, **S**awyer, **S**owing, **S**un, and **W**ater **S**afeguarding **S**ustainable **L**ife.
- **Factor W^n ("WWWW WWWW WWWW WWWW WWWW"):** Rain **W**ater, Green **W**ater, Underground **W**ater, Drinking **W**ater, Potable **W**ater, **W**ater Floods, **W**ater Level, **W**ater Management, **W**ater Scarcity, **W**ater Supply, **W**ater Use, **W**atering, **W**ater Pollution, **W**ater Technology, **W**ater Conservation Technology, **W**ater Agronomy, **W**ater Value, **W**ater Use Efficiency, Tolerance to **W**ater Excess, and Tolerance to **W**ater Deficiency are relevant aspects **S**afeguarding **S**ustainable **D**evelopment.

There is need for a second green ®*evolution* – a green ®*evolution* in agriculture. While global demand for agricultural produce continues to rise, limited arable land, decreasing growth rates of crop yield, water shortages and climate change create enormous challenges on the supply side. To meet these demands now and in the future, we need nothing less than a "second green ®***evolution***". This is an essential necessity, because analyzed yield trends of key crops such as maize, rice, wheat and soybean are insufficient to double global production by 2050 outlined in detail by *Ray et al.* (*2013*).

As an example, over the last 30 years, there were an estimated 470 draught-related disasters around the world (*IPCC, 2012*) and draughts have become longer and more intensive in many regions. By 2050, draught-tolerant crop varieties can enable farmers to adapt to these conditions and can safeguard higher yields around the world (*CropLife International, 2015*). Worldwide yield improvements with draught-tolerance traits will be in a range of 5-7% North America, 11% North Africa, 17% East Africa, 7-9% North Africa & Middle East, 11-12% South Asia, 7-8%, East Asia & Pacific and 11% Oceania (*IFPRI, 2014*) in order to reduce the gap.

Today, the actual challenge is: How to come from improved genotypes *via* functional genomics and gene engineering to fruitful phenotypes in the field – in time?

Up to now, most of plant functional genomics are analyzed in laboratories and greenhouses, but not in the field. This has to be changed as quickly as possible.

As mentioned by *Varshney et al.* (*2014*), fortunately, "the rapid developments in next generation sequencing (NGS) technologies have opened up many new opportunities to explore the relationship between genotype and phenotype with greater resolution than ever before." The modelling of the complex genotype-phenotype relationships of crops is possible and has global relevance.

There is urgent need for high-throughput, cost-effective, quick, and precise phenotyping methodologies that will undoubtedly involve digital image capture, remote sensing, and other forms of digital communication systems (*Reese, 2013*).

By pressing forward **DNA-®*evolution*** of crops through implementation of functional genomics, marker-assisted selection, genomics-assisted breeding, genetic engineering, genome engineering (*Doudna and Charpentier, 2014*), synthetic biology, and digital plant cells as well as the ***IGREEN-®evolution*** (*Kern, 2015*) forward in agriculture through implementation of digital systems such as smartphones, apps, global positioning systems (GPSs), sensors, robotics, drones, unmanned aerial vehicles (UAVs), unmanned ground vehicles (UGVs), and others, the changing world will be able to address **Factor F^n ("FFFF FFFF FFFF FFFF"):** **F**uture **F**arming, **F**ood, **F**eed, **F**itness, **F**uel, **F**iber, **F**lowers, **F**reshwater, **F**ishery, **F**orestry, **F**lora, **F**auna, **F**un, **F**ortune, **F**reedom, which are milestones on a roadmap for tackling the challenges of the 21st Century (*Kern, 2002*).

Let us share the following vision: "To understand the dialogue of genes and develop it further – to decipher, marvel it and understand nature's primary language, to add to it with a sense of responsibility and to make use of it in an ethically acceptable way, for without genes there can be no seeing, speaking, hearing, feeling or smelling – there can be no language, no communication, no dialogue, no art, no ethics, no morality – and no agriculture, no life. To use the primary language of Nature, or: How can we find the way from the secrets of life to ethically acceptable innovations for the future?"

Finally, let me quote *Magini, Ignatz* (*1819*) from Austria:

- *"To acclimatize non-indigenous cereals in our regions, we must reproduce the conditions under which they thrive in their country of origin and as far as possible eliminate the factors which cause them to fail."*
- *"At the same time we should not subject them to excessive artificial refinements, thereby turning them into weaklings attracting a host of diseases which we seldom observe in the wild growing plants."*

In considering and doing all this, we must integrate different scientific fields, including molecular biology, ancient DNA archaeology, genetics, plant breeding, computer science, computer modelling, engineering, biometrics, bioinformatics, and systems biology, so that genomics-assisted breeding can improve crop quality. Last but not least, suitable cultivars have to be provided to farmers – in time!

Farmers, scientists, politicians, the public at large, and young people especially should be encouraged to be optimistic and to go for and improve the DNA-®***evolution*** of agriculture in order to add value to agriculture, to societies and to enable a peaceful life on earth.

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Remarks:

Opinions expressed in this contribution are those of the author.

This analysis will also be published: Manfred Kern, 2015. Vision: The DNA-®evolution of Agriculture.
In: Production and Processing of Food Crops for Value Addition: Technology and Genetic Options.
Eds: R.K. Behl, A.P. Singh, A.B. Lal, and G. Haesaert, Agrobios (International) Publishers, pp 1-6, Book pages 1-347, ISBN: 978-93-81191-05-7.

About the Author of this Issue

Dr. Manfred Kern, biologist, futurologist, managing director of agriExcellence GmbH (www.agriexcellence.de), worked in the chemical crop protection industry for Hoechst AG, AgrEvo GmbH, Aventis CropScience AG and Bayer CropScience AG. Over the foregoing 30 years he has held key positions in science and technology, strategy, marketing and communications.

He has been running the project "Future of Agriculture: Vision 2025/2050", a comprehensive study on the safeguarding of world food supplies, since 1995. Dr. Kern has more than 150 publications to his credit and has given over 1,000 presentations at international/national congresses, conferences, symposia and workshops in over 70 countries.

He has been awarded by various organisations for significant accomplishments in the field of agricultural innovation. In 2007, the secretariat of UNCCD (United Nations Convention to Combat Desertification) recognized Dr. Kern by upholding his title as *"Eminent Person".*

Dr. Kern is also a member of the ISPSW Speaker Management Team. Further information at ISPSW website: http://www.ispsw.com/en/speaker-management/

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