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Gartland, Kevan; Gartland, Jill S.

Published in:
The EuroBiotech Journal

DOI:
10.2478/ebtj-2018-0002

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

The EuroBiotech Journal

REVIEW
Food & Feed Biotechnology

Contributions of biotechnology to meeting future food and environmental security needs

Kevan M.A. Gartland* and Jill S. Gartland

Abstract
Biotechnology, including genetic modifications, can play a vital role in helping to meet future food and environmental security needs for our growing population. The nature and use of biotechnology crops are described and related to aspects of food security. Biotechnological applications for food and animal feed are described, together with trends on global adoption of these crops. The benefits of biotechnology crops through increased yield, reduced pesticide use and decreased environmental damage are discussed. Examples of biotechnology crops which do not involve genetic modification are also described. Applications of biotechnology to drought and salt tolerance, and biofortification in which micronutrient content is enhanced are discussed. Emergent technologies such as RNA spraying technology, use of genome editing in agriculture and future targets for improved food and environmental security are considered.

Keywords: food supply, environmental security, biotechnology crops, biofortification, 'Golden' crops, micronutrients, regulation of gene expression, human health & nutrition

Life Sciences, Glasgow Caledonian University, Glasgow G4 0BA, Scotland

*Corresponding author: K.M.A Gartland
E-mail: Kevan.Gartland@gcu.ac.uk

DOI: 10.2478/ebtj-2018-0002

Introduction

There can be little doubt that global climate change will increase the frequency and severity of extreme weather events. These include floods, drought, smogs and increased temperatures, with a rise of at least 2 °C forecast by 2050 and the need for greater climate justice (1). Climate change is having adverse effects on agriculture, rendering food supply less secure for many in developing countries. At the same time, global population is predicted to increase from 7.3 billion (Bn) in 2015 to 9.5 Bn by 2050 (2), with estimates of 800-925 million (Mn) people under-nourished by 2020 (3,4). 'Hidden hunger' due to a lack of vitamins and minerals is the most common form of malnutrition, affecting more than 2 Bn citizens (4). Achieving food security is a significant global challenge. Key questions include how agriculture can provide enough food to feed everyone from less than 0.2 hectares (ha) per person (or 45 m x 45 m plot) when at least 0.5 ha is needed using current practices (5). Our agricultural systems, trading and consumer behaviours need significant reforms, as currently 35% of food production is wasted (4). Biotechnology can play an important role in addressing many of the issues associated with these challenges. Conventional crop technology, when allied to biotechnology can address these matters. Increased crop productivity, including the use of genetically modified and other forms of biotechnology crops, leads to more affordable food through reduced production costs, less pesticide spraying, decreased soil damage, fuel use and carbon dioxide release through reduced ploughing. Farm income gains through the use of biotechnology crops for 1996-2014 reached $150 Bn globally (6). Environmental security can be enhanced by conserving biodiversity and maintaining forests through increasing productivity of the world's 1.5 Bn ha of arable land. More efficient production will reduce the eco-footprint

Table 1. Four major global biotech crops

Crop Plant	Biotech Crop Plantings 2016 (Mn ha)	Global Adoption
Soybean	91.4	78%
Maize	60.6	33%
Cotton	22.3	64%
Oil Seed Rape	8.6	24%

Source: ISAAA (2016; 10)

of agriculture. From 1996 when biotechnology crops including genetically modified crops were first deployed, to 2014, the environmental impact of herbicide and insecticide spraying decreased by 18.5%, or 583 Mn kg. A 2014 meta-analysis of 147 studies showed biotech crops reducing pesticide use by 37% (7). The reduced carbon dioxide emissions from fewer pesticide applications during this period equates to removing 12 Mn cars from our roads for a year (8-10).

The overwhelming majority of nations (with the current exception of the United States) have accepted the need to modify behaviours to ameliorate and eventually reverse climate change effects, by ratifying the Paris Climate Accord (11). Many barriers to progress and the sustainable exploitation of green opportunities for food and environmental security purposes still remain (12).

Food security

Biotechnology can enhance at least four aspects of securing our food supply in a sustainable manner (1, 13). The availability of food for global consumers can be improved by increasing the efficiency and effectiveness of our primary food production systems, reducing waste during food processing and trade actions, improving access to food supplies through better transport and marketing systems to drive down food costs, improving the buying power of consumers, particularly in developing countries. Food utilisation can also be enhanced, by improving the nutrient status of food choices, for example through micronutrient supplementation by biofortification. Higher standards of food quality and safety, together with doing more to ensure supplies of clean water and adequate sanitation are also very important. Finally, ensuring better physical access to food supplies, at economic prices will help ensure the stability of our food systems at times of massively increasing demand (3, 14). Some estimates suggest that as much as 60% increased efficiency in food production, from a declining agricultural land area will be necessary to meet rising demand in the coming decades.

Biotechnological applications

The ways in which biotechnology can help aid food and environmental security include use of marker aided selection, combined with genomics technologies, in vitro cultivation, genetic modification to introduce valuable traits and a raft of emergent technologies. The US National Academies of Science and the Royal Society have concluded that biotech crops pose no intrinsic risk to human health or the environment (15, 16). Marker aided selection can increase the effectiveness of strategies to identify elite germplasm for stressed environments, which are capable of better utilising scarce resources including water and soil nutrients for food production. Humankind has made substantial progress with this approach, not least through the Norman Borlaug led green revolution. Huge increases in the availability of genomic sequence information on key yield influencing traits will play an ever more critical role in adaptation strategies for our food crops. In vitro cultivation, allied to genetic modification of such elite germplasm, is already improving yields, protecting crops from drought and pathogens and improving the health and nutritional properties of food crops through biofortification (14). Emergent technologies combining elements of precision agriculture with large data sets and artificial intelligence will lead to smarter decision making, greater efficiency and overall productivity. Such approaches can contribute to sustainably meeting the current and future food and environmental needs of society. These needs extend beyond food to include animal feed, fuels, fibre and environmental protection products.

Adoption of biotechnology crops

From the first commercialisation of biotechnology crops in 1996, planting has increased by more than 110 fold, reaching 185.1 Mn ha (458 Mn acres) in 2016, by 18 Mn farmers in 26 countries. This is the fastest adopted crop technology in modern agriculture, with cumulative plantings reaching 2.15 Bn ha, equivalent to 42% of global land area (10). Whilst the four most planted crops remain soybean, maize, cotton and oil seed rape (canola), since 2011 more biotechnology crops have been planted each year in developing, rather than industrialized countries (see **Table 1**). In 2016, 19 developing countries planted 54% of global biotechnology crops on 99.6 Mn ha.

Genetic modification and biotechnology crops have benefitted the environment through decreased chemical pesticide (and associated water) use by 37% since 1996 (17), whilst enhancing crop yields by 22% and increasing profits for 18 million farmers by 68%. Less spraying means decreased emissions of carbon dioxide and greenhouse gases, as well as less physical damage to soils through less tilling (8).

Applications of biotechnology for food, feed and environmental security

In 2016, 1.2 Mn ha of herbicide tolerant alfalfa and 22 kha of low lignin alfalfa were planted in North America. Alfalfa is the

Table 2. Top 10 Countries for Biotech Crop Growth (2016)

2016 Rank	Country	Biotech Crop Area (Mn ha)
1	United States	72.9
2	Brazil	49.1
3	Argentina	23.8
4	Canada	11.6
5	India	10.8
6	Paraguay	3.6
7	Pakistan	2.9
8	China	2.8
9	South Africa	2.7
10	Uruguay	1.3

Source: ISAAA (2016; 10)

world's leading forage crop, and 2016 was the first commercial growing season for the low lignin variety. It was produced using RNAi anti-caffeoyl coA 3-O-methyltransferase technology to reduce lignin content by 20% (18) which allows the cropping cycle to be extended from three to four weeks, with less environmental damage and fewer harvests per year needed (19). Round Up Ready alfalfa has been grown commercially in the United States since 2005. Biotechnologically enhanced sugar beet, squash, papaya, brinjal (aubergine or eggplant) and potato were also grown on a commercial scale in 2016. The effectiveness of biotechnology crops is shown by their global market value of $15.3 Bn in 2016, being 35% of the $45 Bn global commercial seed market, with farm gate revenues ten-fold higher than the value of biotech seeds (8). The world's top 10 countries for growth of biotech crops are shown in **Table 2**. Recently, the European Union has relicensed use of glyphosate for a further five years, emphasising the importance of glyphosate tolerance to agriculture and the potential impact of any future restrictions on use at a global level (20).

Bruising of potatoes (*Solanum tuberosum*) causes 182 kilotonnes (kt) of losses annually in the United States alone. Biotechnology has provided two generations of potatoes with resistance to bruising and black spot disease. JR Simplot's Innate 1 used an RNAi approach to reduce tuber specific expression of poly phenol oxidase 5, by silencing the asparagine synthetase 1 (*Asn1*) gene (21), resulting in <70% less acrylamide production within tubers (22). This trait used only DNA from sexually compatible wild potatoes, avoiding the use of foreign DNA, and was deregulated by the USDA in 2014. Three varieties of Innate 2 (Sim2) have added resistance to late blight disease, the original cause of the 19^{th} century potato famine, using the *Rpi-vnt1* gene from wild South American potato whilst further reducing the acrylamide content by up to 90% when processed at high temperatures. Losses during storage will also be lowered due to sharply decreased reducing sugar content, allowing cold storage at 38 ^{o}F for up to six months without sacrificing quality. Environmental benefits from widespread adoption of these bio-engineered potatoes, could eventually include a 25-45% reduction in fungicide use for late blight disease control, 447 kt fewer wasted potatoes, 64.3 Mn m^3 less water usage, and up to 206,000 fewer hectares (495,000 acres) of pesticide applications in the United States alone. Carbon dioxide emissions could fall by up to 6.6 kt. Innate 2 Russet Burbank, Ranger Russet and Atlantic varieties, which contain only wild and cultivated potato genes, have received US Dept. of Agriculture, Food and Drug Administration and Environmental Protection Agency clearance, for growth and sale in the United States, as well as from Health Canada and the Canadian Food Inspection Agency (23). Marketing consents for import of Innate potatoes are currently being pursued in at least a further eight different countries. 20 years on since the first biotechnology potato, the future use of biotechnology to enhance potato performance and provide pathogen protection in the world's most important vegetable crop seems secure (24).

Okanagan Specialty Fruits, of Canada have used a RNA interference approach, to silence four poly-phenol oxidase genes in Granny Smith and Golden Delicious apple genotypes. These apples, which are deregulated in the United States, have decreased wastage by a reduced propensity to browning whilst retaining other aspects of apple attractiveness (25, 26). University of Florida biotechnologists have demonstrated that losses of strawberry crops due to anthracnose crown rot, angular leaf spot and powdery mildew may be reduced by overexpressing two *Arabidopsis thaliana* 'elongator' genes *AtELP3* and *AtELP4* in woodland strawberry (*Fragaria vesca*). Although not yet submitted for regulatory approval, such elongator genes, which have multiple roles in cell metabolism and plant immune responses, should one day be able to decrease disease severity and fungicide applications in not just strawberry, but other soft fruit species (27).

Biofortification

Nutritional quality can also be improved through biofortification, by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology (28, 29). In rice (*Oryza sativa*) for example, a 150 fold increase in Vitamin B9 folate has been observed by complexing folate to folate binding proteins. This may be helpful to consumers as 50% of folate is normally lost within four months of storage (30). Biofortification in cassava can contribute to increases of 1.9-5.8 fold in bioavailable vitamin B6. Increases of at least 2.3 fold are needed for dietary sufficiency, to guard against heart disease, diabetes and neurological trauma. Elevated B6 levels were obtained by increasing B6 co-factor pyridoxal 5'-phosphate content by expressing the *Arabidopsis AtPDX1* synthase and *AtPDX2* glutaminase genes with strong, constitutive promoters, which are effectively always 'on' (31).

Enhanced provitamin A carotenoids (mostly β-carotene) have been genetically modified into a number of crops and several have enhanced bioavailability to maintain vitamin A levels (28, 32). Probably the best known example of a biotechnology crop which could lead to improved nutritional properties affecting human health is 'Golden Rice', bred by Ingo Potrykus, Peter Beyer and colleagues from around the world (33). β-carotene (pro-vitamin A) deficiency leads to 500,000 cases of child blindness each year. Complications can result in thousands of early child deaths. 'Golden Rice' originally used daffodil and *Erwinia* genes for phytoene synthases to increase β-carotene content, in order to address this poverty based malnourishment issue, with rice grains, accumulating β-carotene giving the characteristic golden hue (34). More than 40 patents have been freely donated by companies, institutes and scientists to this cause. As yet however, and after 20 years of development, 'Golden Rice' is still to be deployed on a commercial scale. This may be due to concerns about modifying such an important staple crop for many countries, to field performance not yet reaching the anticipated levels, or a desire not to be first to deploy (35), in countries such as the Philippines and Bangladesh. Data from American volunteer subjects has shown that 'Golden Rice' β-carotene was highly bio-available and readily enters the bloodstream by human digestion, being converted into pro-vitamin A at a more favourable ratio than other food sources (36). β-carotene in 'Golden Rice' has been shown to be as good as that in oils fed to children as a vitamin A source (37).

The development of 'Golden Rice 2' produced with support from the 'Patents for Humanity' project, enhances field performance further by comparing phytoene synthases from different sources, including maize, pepper, and tomato as well as daffodil and a native rice gene, together with an *Erwinia* carotene desaturase (*crt1*). The maize phytoene synthase has achieved up to a 23-fold increase in total carotenoids, but has still to be commercially released (38). This is currently the most promising approach to enhancing carotenoids in rice. 'Golden Rice 2' is a significant part of, but not the entire solution to the β-carotene deficiency malnourishment issue. Improved agricultural, education and food storage practices, along with use of heirloom seeds for particular environments (35), will also play important roles in addressing the challenge (8, 39). World Health Organisation studies have established that the alternative solution of high dose vitamin A dietary supplementation must be repeated every 4-6 months (40, 41). UNICEF findings show that almost half of 6-59 month old sub-Saharan African children and 44% of South Asian children were vitamin A deficient, with targeted dietary supplements able to reach only two in three children (42).

Potato tubers provide starch and vitamin C and is the third most consumed plant food globally. Opportunities to increase provitamin A and vitamin E content for use in developing countries have been realised by Ohio State University scientists to develop 'Golden Potatoes', using genes from an *Erwinia* mini-pathway for tuber specific α– and β–carotene synthesis (43). The golden tubers contained up to 91 µg/g dry weight vitamin A and 78 µg/g dry weight vitamin E content as well as elevated levels of other carotenoid components. Carotenoid bioavailability after boiling potato cubes and treating cultured CaCo-2 human cells was improved c.f. wild type. A single 150 g serving of these potatoes can provide 42% and 23% of the daily requirement for retinol activity equivalents (a provitamin A surrogate) and 34% and 17% of daily vitamin E needs for children and women of reproductive age (44) and may prove highly useful as vitamin A and E sources for many countries.

Sorghum (*Sorghum bicolor*) is a food staple for 500 million people, notably in arid and semi-arid areas, including parts of Africa where it is the daily staple for 300 million people (45). Vitamin A micronutrient deficiency can lead not just to poor sight and blindness, but also to immune system defects, and is considered as vitally important for survival and physical health in children exposed to disease, with up to 95.6% of preschool children suffering from vitamin A deficiency in some areas (46). Unfortunately, this important cereal is considered nutrient-poor and has only low levels of β-carotene. The relative instability of β-carotene in sorghum adds to the micronutrient problem. Du Pont Pioneer biotechnologists (45) have shown that elevated vitamin E content improves all trans-β-carotene accumulation and stability in biofortified sorghum. Co-expression of homogentisate geranyl geranyl transferase (HGGT1), stacked with carotenoid biosynthetic genes, can mitigate oxidative degradation, leading to enhanced β-carotene accumulation and stability, increasing β-carotene half-life from 4 to 10 weeks (45).

Another alternative approach to the problem of increasing pro-vitamin A availability is being followed by James Dale of Queensland University of Technology with support from the Gates Foundation, amongst others in banana, the world's most important fruit crop. Sterile cooking banana varieties are being used to overexpress the asupina banana *PSY2a* phytoene synthase, with maize poly-ubiquitin or native banana promoters. Sterility prevents gene escape for this food crop, with Ugandan citizens, for example, consuming $\leq$1.6 kg bananas/day. β-carotene content of 20 µg/g dry weight have been achieved using this approach and field trials are currently taking place for possible release in 2020 (48). Recently Dale's lab has also demonstrated fruit pro-vitamin A concentrations of $\leq$55 µg/g dry weight in field grown fruit from the cultivated Cavendish banana, expressing a single phytoene synthase gene from Fe'i bananas , grown widely in Papua New Guinea and Micronesia (49 - 51). Studies with Indian banana cultivars (*Musa accuminata*) carotenoid accumulation in peel and in edible pulp revealed high β-carotene levels of <13.62 μg/g in edible pulp from Nendran, an orange fleshed traditional South Indian cultivar (52), due to the presence of two isoforms of the native phytoene synthase gene *MaPsy1* and *MaPsy2*.

Switching plant hosts in this way may help to overcome some of the reticence to deploy β-carotene fortified food crops. This is demonstrated by the award of the 2016 World Food Prize to biofortified sweet potato researchers (29) for using South American genotypes, able to produce and store high levels of β-carotenes in the breeding of orange-fleshed sweet potatoes with enhanced pro-vitamin A content and acceptable taste properties for Africa. Nutritional studies and education programmes have persuaded two million households in 10 African countries to grow and consume this nutritionally enhanced food. Biofortified crops including beans, rice, wheat and pearl millet as well as vitamin A–enriched cassava, maize and orange-fleshed sweet potato are currently being tested or release in more than 40 countries (29).

Drought tolerance and water use efficiency

As much as 15% of maize yield is lost due to drought. This is particularly problematic for African maize farmers. Initiatives such as 'Water Efficient Maize for Africa' (WEMA) seek to address the complex set of physiological responses related to drought-induced water stress, using hybrids (53). 75% of the most severe droughts in the past 10 years have been in Africa, with 90% of sub-Saharan Africa farmers relying solely on rainfall for what is the staple crop for >300 million citizens. For maize, the 2 weeks prior to anthesis (flowering) and post-anthesis phases, when kernels can be ablated, are critical for yield determination. The availability of maize B73 reference genome sequence and whole genome resequencing of 15 maize inbred lines and common variants has enabled candidate genes for drought tolerance to be identified (54). By combining the best of traditional maize hybrid breeding with improved sustainable agricultural practices and appropriate possible use of novel trait technologies, including genomics and marker aided selection, drought tolerant and ultimately disease resistant hybrids are being developed, to enhance both yield and food security. Royalty-free donations of germplasm, physiological and yield performance data has led to the WEMA conventionally bred hybrids such as WE1101 'DroughtTEGO' which has been deployed in Kenya since 2013, with performance gains of 4-5 t/ha under moderate drought conditions and improved resistance to maize streak virus, grey leaf spot and turcicum leaf blight pathogens (55). This is an important international effort, with maize germplasm and technical expertise donated by Monsanto, the International Maize and Wheat Improvement Center and the African Agricultural Technology Foundation. Additional financial support has been provided by the Gates and Buffet Foundations and USAID (53).

Genuity DroughtGard maize hybrids, which have been bred by Monsanto and BASF combine elite germplasm for North American markets with improved agricultural practice and novel trait technologies to give enhanced performance under mild-moderate drought conditions. *cspB*, an RNA chaperone from *Bacillus subtillis*, has been genetically modified into elite maize varieties to protect key cellular mRNAs from misfolding and enhance hydroefficiency (56, 57). 7% yield gains are obtained for these deregulated hybrid maize, which has also been approved for import to China since 2013, as MON7460. No performance penalty was found in non-stressed environments (58, 59). The Genuity DroughtGard series of hybrids (60) also include combinations of stacked genes, including resistance to particular herbicides and potentially pests such as the European corn borer, for particular settings (61). It is highly likely that approaches such as these, which combine the best of conventional technology with improved decision making and novel trait technologies will enhance yield. This will ultimately benefit the environment through improved use of scarce water; farmers and consumers alike.

Salt-tolerance

Soil and irrigation water salinity can be a major problem for many food crop plants, most crops not being able to tolerate salt at levels 30% of seawater, severely impacting on both growth and yield. There are however, some exceptions to this, reflecting the biodiversity of agricultural crop systems (62). Amongst food and commodity crops with moderate to high salt tolerance, as measured by electrical conductivity, are some genotypes of potato, broccoli, maize wheat, barley and sugar beet (63). Many of these individual genotypes are not however, commercially viable. Understanding and being to enhance salt tolerance in almost any food crop is a desirable target. In barley (*Hordeum vulgare*), for example, growth is reduced upon exposure to NaCl almost immediately, even before Na^+ in the shoot can reach toxic concentrations. Recent studies with 24 Australian barley lines have shown that variation in shoot tolerance mechanisms may not solely be determined by ion toxicity. The most salt-tolerant barley genotypes had both shoot ion-independent salt tolerance and an ability to exclude Na+ from the shoot, maintaining high K^+: Na^+ ratios (64). Quinoa (*Chenopodium quinoa*) is a food crop from South America, which uses the unusual physiological feature of storing salt in bladder-like cells on the surface of leaves. Quinoa transports Na^+ and Cl^- dissolved ions into these salt bladder cells and ultimately into their vacuoles. Sugars transported at the same time provide energy for these active processes (65). The knowledge gained from such unusual physiologies may one day prove useful in breeding greater salt tolerance into other cereals and food crops.

In rice (*Oryza sativa*), 6,000 lines of ethyl methanesulfonate mutagenized 'hitomebore', an elite local japonica cultivar, have been screened to seek out increased salt tolerance (66). The most promising of these mutants, hitomebore salt tolerant 1 (*hst1*) has been further characterised using a mutation mapping approach (67). This has enabled rapid identification of a loss of function mutant responsible for *hst1's* enhanced salt tolerance, by RNA sequencing. *hst 1* has been used to breed a salt-tolerant genotype ' Kaijin', by backcrossing. Kaijin differs from hitomebore by only 201 single nucleotide polymorphisms, whilst retaining the advantageous growth and yield properties of the hitomebore parent under normal growth conditions. This took only two years to reach farmer-ready status (67, 68). Further understanding of how salt-tolerance and salt-sensitivity works in rice may come from the study of micro RNAs (miRomics). Micro RNAs act through transcript cleavage or depressing translation, and a series of such micro RNAs modulate signalling molecules, ion transporters, metabolic enzymes, transcriptional regulators and regulating the plant's response to salt stress (69). Using RNA sequencing data, comparisons with known targets and metabolic pathways revealed the involvement of specific micro RNAS in pathways leading to salt-tolerance or salt-sensitivity using the early growth stage salt-tolerant cultivar Pokkali and the salt-sensitive Pusa Basmati. Modification of micro RNA 5'-ends and isomeric microRNAs (isomiRs) appear to play an important role, which is probably of functional and evolutionary importance (70, 71). Combining these data with new insights from other aspects of plant physiology is likely to lead to increased understanding of the dynamic nature of salt-tolerance (69) and perhaps improved performance.

Emergent technologies

As technology continues to advance, new ways of approaching issues of food and environmental security emerge. Spraying crops with synthetic RNAs to stimulate responses linked to e.g. drought stress is one such example (72), whilst such RNA spraying can also convey resistance to pests such as Colorado beetle in potato for several months. Costing perhaps as little as \$50/g to synthesise, RNA spraying and subsequent interference with pest gene expression may provide a cost effective alternative to some types of genetic modification and pesticide applications (72, 73). Clustered regularly interspersed palindromic repeats (CRISPR) using Cas9 or Cpf1 nucleases are becoming widely used in agriculture (74, 75). This includes precise modifications to knock-in (add), or knock-out (delete) specific sequences where genomes are well understood (76). Meta-analysis of 52 peer-reviewed articles since 2014 confirms use of CRISPR to increase yield, tolerance to biotic and abiotic stress (77) and biofortification (76). Rice and maize are the most targeted crop plants, with most publications coming from China, the USA and Europe. Current advances include the use of 37 ^{o}C. heat-stress to increase the efficiency of targeted mutagenesis in *Arabidopsis* (77) and the demonstration of precision editing of phytoene desaturase in banana (48).

Although not yet fully proven, other approaches such as overexpressing the *Arabidopsis At ERECTA* receptor-like kinase show great promise in increasing thermotolerance in rice and tomato, by delaying senescence, increasing anti-oxidant and osmoprotectant effects (78). Trehalose-6-phosphate phosphatase overexpression can enhance maize yields by 9-12.3% in both well-watered and mild drought conditions, whilst Argentina has released a stress-tolerant Verdeca soya bean with up to 10% yield gains though expression of a sunflower HB4 modified homeodomain leucine zipper. Oak Ridge National Laboratory scientists in New York have recently published details of genes from *Kalanchoe*, *Phaleonopsis* (orchid) and *Ananas cosmosus* (pineapple) that appear to enable different drought-resistant plants to survive in semi-arid conditions (79, 80). These findings, which followed an interdisciplinary investigation using plant physiology, bioinformatics, genomics and biochemical tools alongside a supercomputer, may prove of long term significance in bioengineering for drought tolerance or increased water use efficiency. Initiatives such as these may be some years away from commercial reality, but emphasise that biotechnology is making considerable progress in addressing issues of food and environmental security, which remains one of the great global challenges (14).

Acknowledgement

This manuscript is dedicated to the memory of Professor Mariapia Viola Magni, who passed away in December 2017.

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