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Literature Review

The Journey of Genetically Modified Crops - A Review

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Introduction

To date, scientists have genetically engineered bacteria that produce various kinds of drugs, crops with resistance various kinds of pests and diseases, and beagles that glow in the dark. While these are all relatively recent advances in scientific technology, humans have been altering the genetics of organisms for over 30,000 years. How did the original practice of selective breeding and artificial selection evolve into the concept of genetically modified organisms, as we know it today? Innovators and scientists, who wanted to get rid of the world's most critical problems, have paved the way for GMOs — a path that leads to an unimaginable array of benefits, but also raises extremely important questions. Most of the foods we eat today were created through traditional breeding methods. But changing plants and animals through traditional breeding can take a long time, and it is difficult to make very specific changes. An example is the dog which is considered to be the first organism which was artificially selected by our ancestors. Wild wolves from East Asia joined our ancestors as scavengers when they were still hunters and gatherers. They were domesticated and artificially selected for specific traits. Over the years, so many different traits like height, colour, behaviour, strength, docility, etc was artificially selected that now we have kinds of dogs which do not resemble wolves at all. Genetic engineering allowed plant breeders to take a desirable trait found in nature and transfer it from one plant or organism to the plant they wanted to improve, as well as make changes to an existing trait in a plant they were developing. After scientists developed genetic engineering in the 1970s, they were able to make similar changes in a more specific way and in a shorter amount of time. Genetically modified crops were first introduced in USA in early 1990s and FlavrSavr tomato became the first transgenic crop to be approved by the U.S Department of Agriculture. Soon Bt corn was also approved. Bt cotton was approved in India in the early 2000s which was followed by immense benefits and profits in the cotton industry as the net income increased and there was a profitable yield with less use of pesticides.

The concept of "genetically modified organisms," or GMOs, has received a large amount of attention in recent years. Indeed, the relative number of Google searches for "GMO" has more than tripled since late 2012. Genetic modification is a biological technique that effects alterations in the genetic machinery of all kinds of living organisms. GMO is defined as follows by WHO "Organisms in which the genetic material (DNA) has been altered in a way that does not occur naturally by mating and/or natural recombination".

Genetically modified crops were created to provide resistance to insects, droughts, herbicides and diseases. Insect resistance could provide farmers with protection against pests, lowering costs for buying pesticides. Drought tolerance could help plants retain water and reduce their need of regular irrigation. Genetically modified Rainbow Papaya was resistant to the papaya ringspot virus (PSRV) and it helped the farmers to recover from the crippling effects of this disease. Another reason to create Genetically modified crops was to enhance the nutritional content like soybeans with enhanced oil profile.

Genetic modification technology allows the transfer of genes for specific traits between different kind of species. The lab

techniques used for this purpose is collectively called recombinant DNA technology which consists of cloning genes, splicing DNA fragments and inserting the genes into the host cells. The crops created using this technology have very specific traits according to the need. Insect and pest resistance, increased yields and quality are some of the most common traits in these kinds of crops. Some crops are created to increase the overall nutritional value. An example is Golden Rice which was created to battle the deficiency of Vitamin A.

This literature review gives a brief summary of a few research papers which answer our basic questions regarding what are genetically modified crops, what is the history and the motivation behind creating this technology, what goes into making a genetically modified crop, what is the process of a genetically modified crop production. It gives a brief understanding about the benefits of the genetically modified technology and the risks associated with it and also actively mentions the controversies associated with genetically modified crops, and the overall response of the government, scientific community and the consumers. Arguments against and in favour of genetically modified crops was mentioned. The success story of genetically modified technology in USA, India, Burkina Faso and Egypt was studied.

Figure 1: Genetically Modified foods.

Figure 2: Bt Corn.

Figure 3: Genetically modified crops.

Review of Literature

Chen Zhang, Robert Wohlhueter and Han Zhang [1] gave us a deeper understanding about genetically modified crops, its history, production and also a focus on its benefits and how it was accompanied by potential risks and side effects. They shared incidents of protests where whole experimental farms of genetically modified wheat, golden rice was destroyed and the triggered responses to it. They began talking about what were genetically modified crops and genetic modification. The authors gave a brief history of genetically modified crops mentioning big events in history associated with the technology - Gregor Mendel discovering heredity, DNA isolation by Frederick Miescher, Watson and Crick's double helix DNA structure model, making of first transgenic mice, launching of human genome project, approval of FlavrSavr tomato by FDA, and many others. The authors acknowledged the need of genetically modified crops citing the expansion of population and use of genetically modified crops to eradicate hunger, decrease in arable land and use of genetically modified crops to increase yield. They described the process of genetically modified crop generation. It included 1) Direct DNA transfer using microparticle bombardment and electroporation. 2) Indirect transfer using bacterial vehicle i.e., soil bacterium Agrobacterium tumefaciens. 3) Direct editing of genomic DNA by CRISPR-Cas9. The authors briefly mentioned the agronomic and economic benefits of genetically modified crops along with how the modification of the chemical composition could enhance nutritional value in transgenic food. Examples of golden rice and Amflora was cited. Uses of genetically modified technology to facilitate food processing was briefly described. They acknowledged the potential health and ecological risks associated with genetically modified food. They mentioned

toxicity, allergenicity and genetic hazards as major health risks citing example of "Starlink" maize. They asked what would happen when insects and weeds acquired resistance to human made pressures and how this technology would disrupt the food web. They concluded by recognising that GM technology had its pros and cons and the question whether genetically modified crops should be consumed or not doesn't have a simple yes or no answer.

Sudha Rani M, Satish Y, Rani C, Prasad NVVSD, Bharthi S, Sri Lakshmi B and RatnaKumari S [2] briefed on the history, impact and the current status of genetically modified crops in India, arguments in favour of and against genetically modified crops, controversies and moratoriums associated with genetically modified crops. The authors stated that in order to cope up with increasing losses due to pests and diseases, droughts, lack of irrigation facilities, India's increasing population, poverty, malnutrition, hunger and low level of agricultural productivity, it needed to rely on biotechnology and GM technology to turn the tables around. They mentioned how Bt cotton was a success in India however safety, unsanitary food processing risks needed to be addressed. They acknowledged the achievements of the United States and the potential for India in this field. They mentioned the genetically modified crops grown in the USA, Brazil, Argentina and Canada and how these countries benefited from it. The authors stated the arguments in favour of genetically modified crops citing the statements of Nobel laureate, Father of Green Revolution in the world, Norman Borlaug and Father of Indian Green Revolution, M.S. Swaminathan in support of genetically modified crops. They mentioned the monopoly of multinational companies, increasing rate of suicide by farmers as arguments against genetically modified crops. They touched upon the impact of Bt cotton, the only genetically modified crop under commercial cultivation in India. Bt cotton changed the cotton industry which was under constant crisis by protecting the crop from various pests, reducing insecticide usage, increase in production and yield. They also mentioned the production process of Bt Brinjal, it's benefits and how protests against it resulted in a 10-year moratorium on field trials of Bt Brinjal. A timeline regarding the developments of GM technology in India was also shown which gave light on why India has been slow to accept the technology. The authors concluded talking about how the field trials conducted over the decades showed that genetically modified crops did not pose any threat to public health and the opposition to this technology needed to end. India needed to embrace this technology as more than 50% of its population is engaged in agriculture and the need to increase the yield is dire.

Ruchir Raman [3] gave a brief overview of the challenges faced in commercial agriculture, the solutions provided by genetically modified crops, problems and controversies. Stating the challenges in commercial agriculture, it was mentioned how agriculture employed nearly 1 in every 5 individuals worldwide and how this industry was suffering due to burden on natural resources, population explosion and pest and crop diseases. These problems were deeply discussed mentioning how current agricultural practices couldn't sustain the world population and pests contributed to 20-40% of crop loss. Urbanization, industrialisation and climate change were also referred to as one of the reasons. It was discussed how these challenges were an opportunity for GM technology to bloom and how the technology had surprisingly increased the net income of farmers who embraced it along with increased yield. The success of GM cotton in India was conversed. The development of Bt cotton by Monsanto - Mahyco was studied and the benefits of its implementation was touched upon. Apart from GM cotton, the success of GM Canola in Australia was also briefly discussed. The author also mentioned controversies associated with the technology specifically mentioning the Monarch Butterfly Controversy (1999) and The Séralini Affair (2012). The author concluded stating that genetically modified crops though highly beneficial, was still an imperfect technology with potential toxicity, allergenicity risks. The issue of Starlink maize was raised and the strict regulatory measures were mentioned. The author concluded that thought the technology could solve many major challenges, the scientific community needed to tackle misinformation and unethical researches, implement strict monitoring and regulations. Keeping these in mind genetically modified crops would have a smooth progress in future.

Kumar., *et al*. [4] presented a comprehensive update on the current status and future prospects of genetically modified crops under cultivation and discussed the issues affecting the adoption of the transgenic crops and how these issues were addressed. The authors briefly mentioned the important role of genetic engineering in crop improvements by using different methods to introduce foreign genes or silence expression of genes in crops.

They explained the useful traits that the genetically modified crops provided like tolerance to pests, insects, diseases, herbicides and environmental stress and improvement in nutritional value. They talked about how approximately 525 transgenic events in 32 crops had been approved for cultivation around different parts of the world. They explained the benefits of this technology mentioning increased crop yields, reduced usage of pesticide and insecticides, reduced CO_2 emissions and decrease in cost of crop production. They also explained the controversies and issues associated with this technology mentioning toxicity, allergenicity and environmental risks as main reasons. Chances of gene flow, effects on non-target organisms, and evolving resistance in weeds and insects were mentioned as potential environmental risks. They concluded stating how the transgenic technology was a new beginning in crop improvement however their track had slowed down due to several concerns and how cisgenesis, intragenesis and genome editing techniques could be used as alternatives to the GM technology and how these technologies could be used to develop crop plants without using foreign genes and how this would lead to a higher acceptance rate in consumers to buy transgenic crops and would also lead to faster approvals from authorities.

A. S. Bawa and K. R. Anilkumar [5] discussed about the safety, risks and public concerns related to Genetically Modified foods. The authors defined genetic modification as a special set of gene technology that could alter the genetic machinery of living organisms such as plants, animals and microorganisms. They defined recombinant DNA technology and explained how this technology could be used to create organisms which would thereafter be called 'Genetically Modified', 'Genetically Engineered', or 'Transgenic'. They mentioned soyabean, corn, cotton and canola as the principle transgenic crops grown commercially with resistance to herbicides and insecticides. Some other crops were also briefly discussed like sweet potato which was resistant to a virus capable of destroying the entire African harvest, rice with increased contents of iron and vitamins to battle problems of malnutrition in Asian countries, plants which were capable of withstanding extreme weather, bananas as edible vaccines which could produce human vaccines against infectious diseases, fish that could mature quickly, fruits and nut trees which could have yields earlier and plants with unique properties. The authors discussed how the 21st century had major challenges ready for us and these technologies could dramatically increase our chances of surviving these challenges. They also briefly drew attention towards the risks, controversies and public concerns with genetically modified foods and crops. Most of these concerns were raised on grounds of human and environmental safety, labelling and consumer choice, ethics, etc. Talking about these issues they concluded leaving us with a question whether recombinant technology was beneficial enough to take on the risks of tampering with nature and health concerns.

Clive James [6] discussed the global adoption of genetically modified crops, new traits and crops introduced, progress in African and Arab countries, benefits and future prospects. It was explained how the countries around the world started adopting the GM technology to face the challenges of increasing population, high prices, poverty and global hunger. It was stated that the number of countries adopting this technology increased from 6 in 1996 to 25 in 2008 and how it had been economically and environmentally beneficial for them. The global hectarage of biotech crops showed growth reaching 125 million hectares in 2008. India was 4th in the list of the countries with most hectarage with USA being at the top. The success of herbicide tolerant sugar beet, introduced in 2008 in the USA was briefly touched upon. The success in Africa was also mentioned. South Africa was the only country in the continent to benefit from genetically modified crops but in 2008, Burkina Faso in West Africa and Egypt in North Africa also adopted Bt cotton and Bt maize respectively. The success of Egypt in adopting this technology was discussed. The need for genetically modified crops to be cultivated in Egypt was mentioned and how Egypt's Agricultural Genetic Engineering Research Institute (AGERI) had worked towards this biotech crop technology was briefly discussed and the story of their success was raised. The benefits of this technology were brought up mentioning it's contribution to food, lower prices, lower poverty, hunger and economic benefits. Talking about future prospects, it was concluded that the future of biotech crops looked promising and it was expected that the countries accepting biotech crops would almost double from 25 by 2015 which according to present day data is true as currently almost 65 countries have authorised imports/cultivations of genetically modified crops.

Gabriel Rangel [7] explored the long history of GMO Technology going into details of ancient genetic modification, modern genetic modification, use of genetic engineered organisms, its

controversies and future. The author touched upon the times when the concept of genetics did not exist and still how the process of 'selective breeding' and 'artificial selection' was used to influence genetics. The example of dogs being artificially selected from wild wolves in East Asia along with various traits like size, hair, colour, etc was mentioned. It was also mentioned how corn began as a wild grass 'teosinte' and was selectively bred resulting in what we know as corn. The author later spoke briefly about the birth of modern genetic modification referring to Herbert Boyer and Stanley Cohen working together to engineer the first successful genetically engineered (GE) organism. The author also mentioned the reactions of media, government, and scientists to this new technology and how moratoriums on GE projects was observed. The Asilomar Conference of 1975 debated about safety of these experiments eventually allowing it to continue with strict guidelines in place. The author later brought up the uses of genetic engineered organisms and crops. He talked about how Calgene's FlavrSavr tomato became the first food crop to be approved by U.S. Department of Agriculture, approval of the first pesticide producing crop in 1995 followed by approval of Bt corn in 1996. He touched upon the development of Golden Rice in 2000 to combat vitamin A deficiency. Finally, the author also mentioned the controversies with GE food raising objections based on environment and health concerns. It mentioned the objections raised towards use of Bt corn in USA and the Bt cotton use in India citing concerns of safety and poor yield but was eventually declared void. The article concludes hinting upon the increase of public awareness, louder calls for GE food regulation and mandatory labelling laws. Mentions regarding the potential future uses of GM technology is touched upon. The use of plants with disease and drought resistance, enhanced growth properties is mentioned briefly eventually leaving us with the question whether we are aware of the future that this technology beholds.

The article by FDA gave an insight on the history, production and latest scientific advances in genetic modification technology. It begins with a question on how genetic engineering changed plant and animal breeding. It talks about how the traditional methods of cross breeding and selective breeding were used to obtain desired traits and how genetic engineering has changed the game and the process which used to take years to happen and was difficult now is more specific and requires short amount of time. The articles goes into a timeline of genetic modification in agriculture which covers all of mankind's advancement in the technology. It mentions use of selective breeding in 8000 BC, works of Gregor Mendel, the experiments of Watson and Crick, Herbert Boyer and Stanley Cohen discovering genetic engineering, FDA approving human insulin to treat diabetes, production of FlavrSavr tomato, approval of genetically engineered salmon by FDA, etc. It briefly explains how GMOs are made. The steps of identification of genetic information, copying the information, insertion of information into the DNA, growing of new organism are explained properly. The example of Bt corn is cited to help understand the process of making a GM crop. The article concludes mentioning the latest scientific advances which include genome editing and tools for it, such as CRISPR-CAS9 and how these technologies can be used to make crops more nutritious and resistant to pests, insects and harsh environmental conditions [8].

Key Points

- The concept of "Genetically modified crops" has received a large amount of attention in recent years. The searches for GMO have tripled since 2012. It was observed we are under tremendous pressure to find out solutions to our existing problems.
- Expansion of population was stated to be one of the big problems. Current global population is approximately 7.35 billion and is estimated to reach 9.7 billion by 2050. It was estimated that around 795 million people in the world are undernourished. It was noticed that the best solution for this was to increase the crop yield from 1.7% to 2.4%.
- It was observed how the GM technology as we know today didn't come up in a day or a year. Herbert Boyer and Stanley Cohen who engineered the first genetically engineered organism in 1973 gave us the first breakthrough in GMO Technology. It also led to controversies and moratoriums which eventually lead to genetic engineering experiments being practiced under specific guidelines.
- Calgene's FlavrSavr tomato was the first food crop to be approved by the USA. Bt potato and Bt corn were later approved. Golden rice was approved by 2000.
- It was observed that Microparticle bombardment, Agrobacterium mediated recombination, genome editing were some of the methods used for genetic engineering.

- United States had the highest area under genetically modified crops, 75mh. According to the ISAAA, the 75 mh GM acreage comprised 34.05 mh soybean, 33.84 mh maize (corn), 4.58 mh cotton, 1.22 mh alfalfa, 0.876 mh canola, 0.458 mh sugar-beet, 3,000 hectares potato and around 1,000 hectares each of apples, squash and papaya.
- Brazil's total 50.2 mh GM crop area included 33.7 mh soybean, 15.6 mh of maize and 0.94 mh of cotton. Argentina had 23.6 mh GM crop area which comprised 18.1 mh of soybean, 5.2 mh maize and 0.25 mh cotton, while it was 8.83 mh canola, 2.50 mh soybean, 1.78 mh maize, 15,000 hectares sugar-beet, and 3,000 hectares alfalfa in the case of Canada's total 13.1 mh.
- ISAAA's latest global report (2017) showed farmers across the world planted 189.8 mh under transgenic crops last year. This is as against 1.7 mh in 1996, the year when they were grown commercially for the first time.
- It was observed that India has the world's fifth largest cultivated area under genetically modified (GM) crops, at 11.4 million hectares (mh) in 2017. Bt cotton was the only genetically modified cash crop under commercial cultivation. This crop helped to reduce the usage of insecticide from 46% in 2001 to less than 26% in 2006 and eventually 21% in 2011. The spending on insecticides went from Rs 7180M in 2004 to Rs 1100M in 2009.
- Bt Brinjal was another crop whose development process was similar to the Bt cotton. However, as it was a food crop, there were concerns regarding its safety eventually leading to a 10-year moratorium on field trials of all genetically modified food crops.
- GM Technology had its fair share of problems. Risks associated with allergenicity, toxicity and other health hazards were raised. There were protests and controversies associated with adoption of this technology. Some countries banned the use of genetically modified crops whereas some countries issued moratorium on field trials.
- It was observed that by 2010, 29 countries had planted commercialized biotech crops and 31 countries had granted regulatory approvals.
- USA was the leading country in the production of GM foods in 2011, with 25 crops receiving regulatory approvals. Data showed that 92% of corn, 94% of soybeans and 94% of cotton produced in the USA was genetically modified. It was seen that there was an increase of more than 370 million tons of food crops from 1996 to 2012.
- In absence of biotechnology, an 11% increase in arable land would be required to reach this feat. It was also observed that in 2006-2012, the global farm income from genetically modified food showed an increase of $116 billion.

Conclusion

The question whether we should be consuming genetically modified food or not does not have a simple "yes" or "no" answer. You need to have a very wide knowledge on not only in genetic engineering, but also in molecular biology, economics, animal and microbial ecology to be able to give an easy answer.

The pros and cons of the technology has been stated. The advantages of using genetically modified crops are far more than the risks attached to it most of which are only unintended and estimations. Humans have continuously adapted to changes to be able to survive this long and we need to be acceptable to changes for our better future. This does in no way or form mean that we should ignore all the risks and unknown possibilities with this technology. But to completely ignore it and not even give it a chance is also very unscientific.

Drawing from the past experiences, it is very unlikely that this technology can be stopped and it shouldn't be stopped. Proper testing needs to be done. Public safety should be considered top priority. The scientific community needs to come together to tackle misinformation and unethical research. Regulation, monitoring and maintenance should be made stricter.

With all of these measures, genetically modified crops will bring productivity and profitability in commercial agriculture for a smooth progress towards the future.

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