Genetics And Plant Breeding

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ABSTRACT –

Genetics is a wide branch and a current research topic in science. Plant breeding uses more of techniques related to modification of genes to attain desired variety of plant. Therefore, genetics has wide application in plant breeding. Traditional breeding techniques took years for attaining the plant with desired traits. Still there were no 100% results obtained. The plant would still lack 1 or 2 desired traits. These traditional breeding processes were very time and cost consuming. However, to overcome this issue, advancements were much necessary to be made. New technologies in genetics were important to ensure satisfactory results in lesser time.

Scientists have come up with genetic alterations which would help induce desired traits into the plant. This is done by various methods, one of them is gene editing technique. Technique of gene editing helped us in developing such a plant which would result in all the desired traits on it. This was a one of remarkable research.

From agricultural perspective, speed breeding technology was a boon as it would help us obtain more yield of higher quality in lesser time. It enables us in providing nutrient rich food to larger population.

This article focuses more upon such recently developed technologies in plant breeding which are of utmost importance in Agricultural as well Food industry.

Keywords – Genetics; CRISPR-Cas9; Plant breeding; Gene – Editing; Speed Breeding; Vit B3; trpA; tryptophan; AI based technologies.

I. INTRODUCTION

Plant breeding is that branch of science dealing with modifying/changing the traits of plants to get desired results and have satisfactory outcomes.

Most of human and animal needs are fulfilled by plants in direct or in an oblique manner; be it our food, clothing or shelter, plants contribute to all the vital needs of other organisms, keeping the interdependency balanced.

Plant breeding is necessary in order to provide sufficient amount of it for various purposes. Growing them and providing all important nutrients in various forms are important. These various forms include fertilizers, injectors, etc.

This concept of plant breeding has ancient roots since human began to live in a civilization. The very basic and ancient form of plant breeding can be considered as 'farming'. It was widely practiced since then with the aim of fulfilling food needs, etc. Due to minimal knowledge known and no advancements in plant breeding, very basic methods were used in plant breeding which relied on observational and selective practices.

These methods included seed selection, asexual propagation, cross pollination, selective pairing and lastly observation. Such methods were trial and error sort of and were slow, time consuming. To

decide a perfect combination or a perfect crop which would yield maximum with benefits & was able to fulfil the purpose, took very long time and efforts.

Therefore, advancements were much needed to make it effortless, timesaving. These basic breeding methods/techniques led to the foundation for the upcoming advanced technologies.

It all began when Gregor Mendel's pea plant experiment gave him remarkable results in genetics of the plant. This is where genetics of plant breeding came into picture and researches began. New discoveries were made in how genetics played an important role, structure and nature of genetic material, its traits and how could we modify them to bring about desired outcomes.

➢ Few remarkable discoveries in advancements of plant breeding and genetics are –

- Mendel's law
- Hybridization
- Green revolution
- Application of molecular biology and genomics
- Genome selection

These milestones were stepping stones towards inventing new technologies in genetics and plants breeding.

To incorporate maximum beneficial traits in one crop and to improve the overall genetic makeup of plant was the main aim of plant breeding.

The effect of these advancements is -

- Availability of specific nutrients where in region lacking it
- Nutrient rich plant
- Natural way to overcome deficiency
- Disease resistance crops
- High yield
- Flexibility to changing climate

These all effects led people to adapt such modified plants on higher scales.

Increasing the nutritional value and bioavailability of that nutrient in a crop will help us solve many health issues related to deficiency. This can be achieved by understanding and then modifying the plants at genetic level.

For e.g., GOLDEN – RICE - This variety of rice was genetically modified in such a way that it could produce beta-carotene, which is a precursor of Vit-A. By such modification at genetic level, it was helpful to those people who were Vit-A deficient. Golden rice provided beta-carotene which was then converted to Vit-A in the body via enzymatic cleavage. Therefore, this crop was remarkable and much more beneficial to food industry. This helped deficient people to avoid taking supplements and overcome the deficiency naturally.

Another example of it is RAINBOW PAPAYA – This GMO crop was resistant to papaya ringspot virus. This ringspot virus was widely spread in farms of Hawaii. This genetic modification led the crop overpower the virus and not get affected by virus. This modification was very important from agriculture perspective as it reduced the loss to the farmers.

Therefore, we can say that plant breeding and genetic modifications assisted the science in producing the desirable crops and proved to be a boon in Food industry as well as Agriculture industry.

Modern technologies that are bonus in plant breeding are -

- Gene - Editing
- Speed Breeding
- Marker Assisted Breeding
- High Throughput Sequencing

- QTL Mapping
- Mutation Breeding

AI based are –

- Machine learning for trait prediction
- Climate Adaption in Crops
- Bioinformatics
- Phenotypic Prediction
- Crop designing
- Disease prediction and Management
- Virtual Plant Breeding

II. GENE – EDITING

Gene editing is being researched many years but the invention of CRISPR/Cas9 – a protein was a breakthrough in this technology in the year 2012. It enabled scientists to apply this technique in agriculture, animal, biotechnology industry.

Gene editing is process where in undesired gene is removed totally or modified by replacing the desired gene by CRISPR-Cas9 protein which acts as a scissor (Bhardwaj, 2022). Also, addition of new gene becomes possible through this technology.

This has wide application in plant breeding as it helps us in obtaining a plant with all the desired qualities.

Let us understand this recent technology through an example.

Suppose we need a plant variety which would be helpful for those who are Niacin (Vitamin B3) deficient due to lack of sources of Vitamin B3 such as fish, poultry. For this we need to genetically modify the plant which would produce the precursor – tryptophan of Vit B3.

First, we need to isolate the desired gene producing tryptophan. Gene responsible for tryptophan production is trpA. Bacteria such as E. coli & Bacillus subtilis contains gene trpA. This trpA gene is isolated from these bacteria using genetic techniques. For further process of gene editing techniques, the steps involved are -

A. Design the gRNA – The targeted DNA is identified and its sequence of nucleotides is known. A guide RNA containing a part of nucleotide sequence complementary to the targeted DNA sequence is designed in order to locate the targeted DNA.
B. Introducing gRNA and Cas9 – At this time the gRNA and Cas9 is introduced in the plant cell, along with the desired isolated gene. This gRNA containing the complementary sequence will locate the DNA simultaneously guiding the Cas9 protein to the site.
C. Cleavage of DNA sequence – After binding of gRNA to the targeted site the Cas9 protein cuts at specific site which is to be modified.
D. Repairing – Cell has its own mechanism of repairing the cleavage site. The desired gene template which was inserted earlier will be used by cell during the repairing process.
E. Growth – After this whole process, as plant grows, gradually this replaced gene will now produce the precursor tryptophan.

When this plant will be consumed, the precursor – tryptophan, an amino acid will be provided to the body in sufficient quantity. This tryptophan will now undergo enzymatic reaction in the body by

enzyme - tryptophan dioxygenase. After going through kynurenine pathway which is a series of enzymatic reactions, tryptophan will be successfully converted to Niacin (Vit B3) in the body.

Here, our main purpose of providing tryptophan for the synthesis of Niacin has been accomplished by this technology. This technology also solves the problem of availability of nutrients in an area. In this case the people will no longer need to rely on the original sources like fish or poultry. This plant will provide adequate amount of it also this would be an option for vegetarian people too. Also, people would have a choice of not taking supplements and rely on higher quality natural source for their deficiency. Making high quality food becomes possible through this technique.

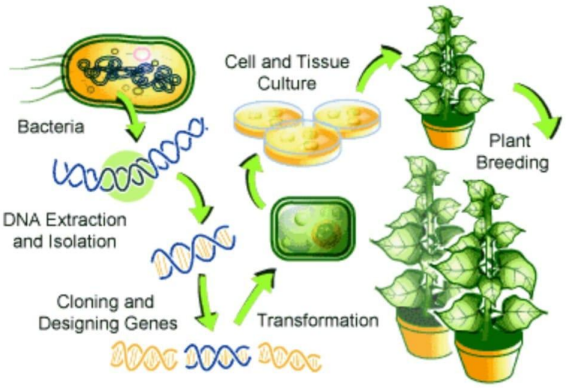

Fig. 1 Gene Editing in Plants

III. SPEED BREEDING

Speed breeding technique was being developed in the year 2010-2011. But it got its recognition in 2016 frow where it started to emerge in the agricultural field. This technique was a remarkable discovery for harvesting long day plants. It works on the principle of providing controlled and optimized growth conditions in order to decrease the growth period, so that more yield is obtained in lesser time.

Speed breeding doesn't include any of the internal changes such as genetic modification. It is totally based on external factors/conditions.

Firstly, a genetically modified plant or a plant with all the desired traits is selected. Let's suppose, this plant is a long day plant which takes longer time to grow or to generate multiple generations of plants. We could provide controlled and enhanced growth conditions such as

A. Proper light source – Here, we provide an artificial LED light source to the plants, for e.g., Helio spectra lights. Each crop needed light with different properties. Accordingly, the intensity, wavelength and the light spectra were modified. One major criterion was the wavelength of light, because each wavelength has different capacity to penetrate. Green lights (495-570nm) were majorly used in thick-walled plants as it had more penetration power that red and blue lights. Red light (600-700nm) accelerates the flowering process essential for breeding. These red lights initiates the conversion of photoreceptor proteins - Pr(phytochrome red absorbing) which is in inactive state to Pfr (phytochrome far-red-absorbing) which is an active state. The Pfr protein is involved in many developmental processes such as flowering, stem elongation, seed germination, etc. (Wang, 2004). Therefore, providing red light with high intensity will help in carrying these processes faster than the time required naturally. Blue light (400-500nm) plays a crucial role in photosynthesis. The blue lights activates the photosystem II (a multi-protein complex found in organelles responsible for photosynthesis) which includes proteins, pigments and much more. When blue light is provided it is absorbed by chlorophyll and other photopigments. The energy gained by the blue light excites the electron in the pigments. This excitation further carries out the photosynthesis. It activates the photosystem II Therefore; blue light is essential in earlier stages of photosynthesis. These all lights are provided for 22-24 hrs with continuous illumination which results in faster growth rates.

B. Temperature control – Drastic or abrupt change in temperature may lead to destruction of temperature sensitive enzymes in plants. This would stop the growth process. The desired temperature must remain constant throughout the process unlike changing climate conditions in natural environment. Majority of crops rely on 20 – 30^0 C for maximum growth. Maintaining the required temperature speeds up the growth process.

C. Humidity control - High humidity results in less water loss. Majority of plants need 60 – 80% humid climate. This is controlled by humidifiers by releasing water vapours in the environment which helps in maintaining high humidity. Therefore, it accelerates the growth process.

D. Nutrient supply - Fertilizers rich in nutrient needed by that plant is provided to ensure healthy growth and faster multiplication of crop.

There are many other controlled factors which needs to be checked, but the above 4 factors are the prioritised ones. By such modifications of external factors, plant growth is promoted and fastened based on how far the environment stays controlled.

Such techniques are widely used in agricultural sector. It yields higher in very lesser time, which would eventually provide more quantity of food to larger population.

Recently, speed breeding technique was experimented on wheat crop. (Alahmad, 2018)

Usually, a wheat crop to grow and mature completely took approximately 100-155 days. Later when experimented speed breeding technique on wheat crop, it took not more than 32-48 days to completely mature.

From this we can conclude that, for a wheat crop, using speed breeding we can yield 3 times more than the natural method in same amount of time, i.e., within 100-155 days. Therefore, there is no debate that on which method should we rely on for faster yield.

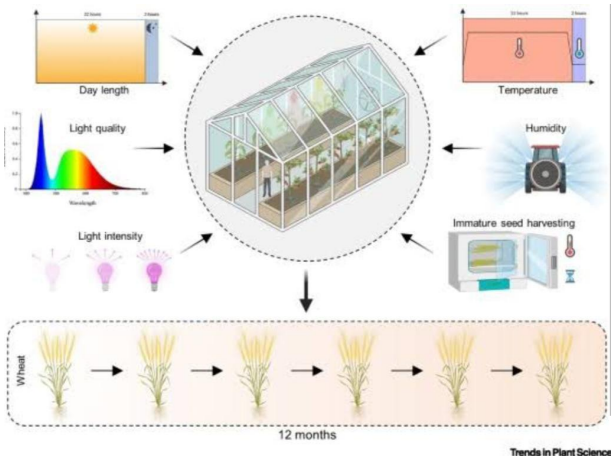

Fig. 2 Speed breeding

IV. AI(Artificial Intelligence) Based Technology

AI based technologies provide us with predictions of outcomes. It helps us design nutrition rich crops.

Virtual Breeding is very recent technology which is completely AI based (Khan, 2022). Many breeding strategies can be designed using computed models of plants. This minimizes the time taken to actually grow the plant and test it.

Virtual breeding begins with the process of feeding the data such as genomic information, the characteristics of the crop, environment provided to the crop, nutrition needed for the growth, etc. By analysing genomic information, AI can evaluate the genetic potential of the plant. Now using this information, combinations are made which would give the desired plant traits, virtual model of crops will be designed using AI technology. This would provide us a virtual simulation scenario of plant breeding.

After all, the outcomes of that plant grown will be displayed. The phenotypic effects of that plant would be obtained. The outcomes include – time taken to mature, traits in the plant, it's over all behaviour, its nutrition, risks associated with it, etc. Two methods of AI such as ML (Machine Learning) and DL (Deep Learning) are used for designing high-precision virtual model and to attain the various responses of Genetically Modified Virtual Plant.

Even it is capable of suggesting few breeding strategies. Therefore, it provides us the overall pros and cons of our breeding strategy. Such technology helps breeders to come up with a perfect formula of plant breeding with higher efficiency.

Today, making use of such AI based Virtual Breeding technique, a breeder already has the whole information about its breeding strategy beforehand, even before actually implementing it.

V. CONCLUSION

We saw that how scientists have invented a lot many things in the field of genetics & its application in plant breeding. Be it Gene editing, Speed breeding, Marker assisted breeding, AI based technologies, all these have wide applications in plant breeding. We do not have to rely only on the traits which plants have naturally in them. Today, we are able to make desired species of plants with improved quality. This enables us to solve many problems related to agriculture, providing nutrition rich food, avoiding intake of supplements, etc.

The above-mentioned technologies also help save time in comparison with the primary methods of developing a plant with desired traits, also the number of trials is minimal in this modern technology to reach the goal of the technology.

Application of AI in plant breeding and genetic is already being used in a good range. Still more invention in AI based technologies are on their way to make every research as fruitful as possible. We need to adapt to these technologies & apply them to go one step closer towards progress in each field.

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