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GENETIC ENHANCEMENT IN COTTON

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PREFACE

Cotton is the most important source of natural fibres and plays a dominant role in country's agrarian and industrial economy. Now-a-days, genetic enhancement or pre-breeding is gaining increasing ground as an importance in all the major crops. With the renewed interest and emphasis in Plant Genetic Resources (PGR) activities, it has become increasingly important to utilize the collected genetic diversity. Genetic enhancement plays an important role in utilizing unadapted and unutilized germplasm collections and creating vast genetic variability for development of productive cultivars / hybrids.

This bulletin is first of its kind that provides comprehensive information about various aspects of genetic enhancement and pre-breeding. This bulletin covers various aspects of genetic enhancement such as definition, need for genetic enhancement, germplasm and genetic enhancement, gene flow and genetic enhancement, methods of genetic enhancement, biotechnology for genetic enhancement, genetic enhancement in cotton, achievements in other crops, advantages of genetic enhancement, and problems associated with genetic enhancement. The information contained in this bulletin has been gathered from various published sources.

Hope this bulletin would be useful to researchers, teachers and students engaged with breeding of field crops in general and cotton in particular. We are thankful to Mrs. Rama Iyer, Stenographer for rendering secretarial help. We are also thankful to Shri. Prafulla Raut, Research Associate for his help in the preparation of this bulletin.

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CONTENTS

1. Introduction

The term "enhancement" was first used by Jones (1983) which according to him can be defined as transferring useful genes from exotic or wild types into agronomically acceptable background. Rick (1984) used the term pre-breeding or developmental breeding to describe the same activity. Thus "genetic enhancement" or "pre-breeding" refers to the transfer or introgression of genes or gene combinations from unadapted sources into breeding materials (FAO, 1996) However, enhancement has been more popularly adopted by PGR scientists. It is an emerging concept emphasizing the use of plant genetic resources. There is very little difference between genetic enhancement and traditional breeding. Enhancement does not include cultivar development and refers only to the improvement of germplasm. Enhanced germplasm can be' more readily used in breeding programmes for cultivar development. Pre-breeding does not differ significantly from general framework of plant breeding and is considered as prior step of sustainable plant breeding. The pre-breeding consists of identifying a useful character, capturing its genetic diversity and putting those genes into usable form. Pre-breeding leads to value addition in the germplasm.

2. Need for Genetic Enhancement

To meet the market requirement, plant breeders have to develop improved cultivars, which is possible through use of elite breeding material which is developed through pre--breeding. In the past, more attention has been given to adaptation and performance through selection than to generation of new variability to fulfill immediate needs.

In the past, crop improvement has led to narrowing down of genetic base resulting in slower progress (genetic gain) in plant breeding and increased risk of genetic vulnerability. This has resulted in the accumulation of unused potential germplasm. In order to break these bottlenecks and to create superior gene pools, genetic enhancement or pre-breeding is required to enhance the value of germplasm.

3. Germplasm and Genetic Enhancement

Germplasm plays an important role in improving the crop cultivars in terms of various useful characters of cotton such as given below:

1. In improving the level of resistance to biotic and abiotic stress.
2. In improving quality characters such as fibre length, strength, fineness, maturity and uniformity.
3. In developing early maturing genotypes, which can fit well in multiple cropping systems.
4. In developing plant types suitable to machine picking etc.
5. Use of germplasm will help in broadening the genetic base of cultivars as well as in creating vast genetic variability.
6. It will also help in value addition of different genotypes through genetic enhancement.

(i) Use of Exotic Germplasm

Exotic germplasm refers to all the germplasm that do not have immediate usefulness without selection for adaptation in a given environment (Haullauer and Miranda, 1981). Exotic germplasm has to undergo conversion or pre-breeding to find its best use in plant breeding.

Most plant breeders fear using exotic or un-adapted material due to its initial detrimental effects on elite breeding material (Kannenberg and Falk, 1995). There are some major constraints in the direct use of exotic material in the breeding programmes which are given below:

(a) Crosses with exotic material can result in the concurrent introduction of inferior alleles and disruption of co-adapted gene complexes in the elite material.

(b) Exotic germplasm can negatively affect adaptedness when introduced in locally adapted genetic base.

(c) The linkage of undesirable genes with desirable traits is a major constraint to increased utilization of un-adapted or exotic germplasm. This acts as a barrier in promoting useful gene flow from exotic to the adapted gene pools.

Exotic germplasm has to undergo "conversion or pre-breeding" to find its best use in plant breeding. In spite of best efforts it is realized that for most of the crops the genetic gap between elite adapted gene pools and exotic pools is growing larger with each breeding cycle. Better knowledge of underlying genetic differences between adapted and exotic germplasm could help to overcome such barriers to gene flow. Studies on cotton have indicated ample scope for genetic enhancement. In some crops like wheat the number of exotic land races introgressed in to elite germplasm is increasing overtime.

(ii) Genepool for Crop Improvement

Three types of germplasm namely, primary, secondary and tertiary are used as genepools. Each of these categories of genepool has its own significance and limitation. In the past, primary gene pool was extensively used for genetic improvement of different crops with a view to create vast genetic variability and broadening the genetic base of breeding material. The use of secondary and tertiary gene pool helps in creating vast genetic variability for various traits. Recently, the work on use of secondary and tertiary gene pool in cotton has been intensified and as a result vast genetic variability has been created for various economic characters such as resistance to biotic and abiotic stresses, fibre quality parameters, plant type etc. Quite recently, the advent of biotechnology has given rise to a new genepool concept, the quaternary genepool. Here the genepool consists of varieties or crops having value added traits evolved through biotechnological approaches. Both cultivated as well as wild germplasm can be utilized for above purposes. The cultivated germplasm will help in broadening the genetic base.

4. Gene Flow and Genetic Enhancement

The movement of various alleles from exotic or unadapted or wild germplasm to the cultivated genotypes is called gene flow. Various isolating mechanisms prevent natural hybridization between cultivated and wild plants.

The natural gene flow has been observed in many crops. However, very little work on artificial gene flow has been done in different crops. Repeated cycles of hybridization and polyploidy have played an important role in the evolution of wheat, sugarcane, potato, sweet potato, yams and plantain. Polyploidy acts as a barrier to gene flow from wild progenitors into the cultivated gene pool, because ploidy difference leads to cross incompatibility. In most instances gene flow from the progenitors into the primary genepool of allopolyploids cannot be promoted by regular crosses and requires the use of embryo rescue and other wide crossing technologies. Many wild *Solanum* species can readily be crossed with the cultivated potato once their ploidyhood is experimentally adjusted by chromosome doubling or haploidization. The importance of broadening the genetic base for disease resistance in crops through the use of wild germplasm and gene deployment strategies has been suggested by some workers (Lean and Wood, 1991). Exotic wild germplasm can contain useful loci for many, quantitative and agronomic traits. Such 'hidden' or cryptic wild loci contributing to qualitative traits can not be screened for unless evaluated in the genetic background of the cultivated genepool- i.e., cultivars or breeders lines.

5. Methods of Genetic Enhancement

There are two major approaches to genetic enhancement or pre-breeding.

(a) Introgression :

Introgression is transfer of one or more genes from exotic/un-adapted / wild stock to adapted breeding populations. This is achieved by making crosses between the donor and the recurrent parent. The concept of introgression through backcross was evolved by Dr. Edgar Anderson and in cotton it was first visualized by Knight (1945).

In backcross method, the parent from which desirable genes are to be incorporated is used as donor parent and the parent which is to be further improved is used as the recurrent parent. Six generations of conventional recurrent backcrossing are required to transform a genetic stock. This method leads to accumulation of genes resulting in enhanced level of genetic expression for the trait. There are three modes of backcrossing as per the need.

(i) **Recurrent backcross:** This method involves successive backcrossing of the cross made between donor and the recurrent parent with the recurrent parent with or without selection. With this method, the monogenic or oligogenic traits with high heritability can be easily transferred.

(ii) **Inbred backcross:** This method involves a limited number of backcrosses (usually one or three). This is followed by several generations of selfing. This method was first given by

Wehrhahn and Allard, 1965. This method results in the development of a population of more than 50% of lines that are homozygous and have a common genetic background similar to the recurrent parent. This method has been used successfully to transfer quantitative traits from exotic germplasm into elite adapted genetic stocks. e.g. improvement of nitrogen fixation and seed protein content in common bean (Bliss, 1985).

(iii) Congruity backcross: This method was originally proposed by Haghighi and Ascher, in 1988. In this method, backcrossing is done to both donor and recurrent parent in alternate generations. This method was used successfully to recover progeny with increased fertility from *Phaseolus vulgaris* and P. *acutifolius* crosses. It was possible to obtain progenies with intermediate morphologies rather than morphologies resembling one or the other parent. This led to effective recombination through the increased levels of heterozygosity.

(b) Incorporation:

Incorporation refers to a large scale programme aiming to develop locally adapted population using exotic / un-adapted germplasm. This was first suggested by Simmonds (1993). In contrast to introgression, incorporation aims at indexing the crop genetic base. The following are the genetic principles of incorporation.

a. Use of material covering wide range of variability
b. Use of un-adapted introduced material
c. The process is complementary to conventional breeding
d. The breeding methods will depend on the biology of the crop, its breeding system and reproduction behavior
e. Maximizing recombination through cyclic or recurrent crossing.
f. Testing for adaptability under diverse agroclimatic conditions
g. Local genetic adaptation - horizontal resistance (HR) to disease
h. The outcome of an effective base-broadening programme will be enhanced genetic variance in economic characters and either good materials *per se* or good parents for crossing into established programmes.

Thus, base broadening ultimately results in the development of potential parents either from adapted stocks through the use of unadapted stocks. e.g. day length adaptation and disease resistance in potatoes.

(c) Other Breeding Approaches:

There are other conventional approaches to enhance the genetic potential of a germplasm in addition to the various backcross methods. They are: (i) convergent improvement, (ii) modified convergent improvement, (iii) strain crossing, (iv) multiple strain crossing, (v) development of composites / synthetics, (vi) decentralized breeding, and (vii) participatory plant breeding. These are briefly discussed below:

(i) Convergent Improvement:

It was originally proposed by Richey (1927). This method involves crossing two (lines A and B) and then backcrossing the resultant single cross independently to both the parental lines. Selection and maintenance of progeny records are practiced during each cycle. The main objectives to improve both the lines simultaneously by incorporating important traits from line A to line B and also the same from line B into line A.

(ii) Modified Convergent Improvement:

This method was first proposed by Henning and Teuber (1996). In this method, multiple populations are crossed. Selection is practiced for a single trait or a combination of traits. The principle underlying this method is that allelic frequency for all traits accumulate in each population through repeated cycles of both selection and introgression. The outcome of the approach is formation of four types of populations viz., three trait, four trait, five trait and six trait populations.

(iii) Strain Crossing:

This method was proposed by Busbice *et.al.* 1972. The concept is that a trait controlled by additive gene action will have a level of expression equal to the mid parent value following strain crossing. Furthermore, if dominant gene action controls the expression of pest resistance traits, then F_1 populations will exhibit resistant levels similar to those observed in the resistant parental strain. In general, strain crosses with one parental strain exhibiting high levels of the desirable trait and the other population possessing moderate to high levels of the same desirable trait manifest the best performance. Thus, the goal of multiple pest resistance and multiple trait selection involving inter-population crosses is to make crosses between parental strains exhibiting moderately high to higher levels of expression for all traits.

(iv) Multiple Strain Crossing:

This method was first suggested by Currier and Melton in the year 1990. This is slightly different from strain crossing and is called multiple strain crosses where more than two populations, each possessing a unique characteristic in high frequency, are simultaneously crossed. Development of multiple strain crossed base populations (strains) requires three cycles of selection for one trait per population with phenotypic recurrent selection. Base populations are then crossed in a multi-population cross at the end of selection to develop the multiple strain cross population. Four types of theoretical multiple strain cross populations can be developed, viz., three-trait, four-trait, five-trait and six-trait populations.

(v) Development of Composites / Synthetics:

This method was first proposed by Harlan and Martini in 1929 in barley. Following are the steps involved in this method:

- Crossing among large number of varieties of diverse origin and genetic make up.
- Creating a heterogeneous population of recombinant types and parental types.

Planting of population under normal conditions to evolve locally adapted genotypes. Merits and demerits of this method are given.

Merits

- The material developed can be used as mass reservoirs of genetic diversity.
- It is effective in retaining local genetic diversity.
- It is effective when adopted under optimum management conditions.
- No skilled labour or detailed record keeping is required.
- It is useful in improving local adaption.

Demerits

- The major drawback of the method is the length of time required to produce new varieties.
- It takes approximately F_{15} generation for developing desirable genotypes.

(vi) Decentralized Breeding:

This method mainly refers to fundamentally two different processes namely decentralized selection and / or decentralized testing. The term 'Decentralized Selection' was first suggested by Simmonds (1984). This is defined as selection in the target environment. The target environment refers to climate, soil, farming systems and management. In self pollinated crops, selection of early segregating populations (F_2) in a number of locations representing target environment is done. This method consists of following steps:

- Crosses are made at the institutional level.
- Material advanced as bulks (without any selection) to F_3 generation.
- Distribution of the segregating material to national programme.
- Selection between populations is made in the target environment in each country.

This method has been useful for genetic enhancement of germplasm in barley and lentil at International Centre of Agricultural Research in Dry Areas (ICARDA). The important merits of this method are presented below:

- It is very powerful in maintaining genetic diversity.
- The effect of this method on genetic variability is larger in marginal environments.
- For better adaptation it may also be useful in favourable environment and rely less on the use of inputs.
- It creates a true partnership with the scientists in the national programmes. It helps to continuously adapt the breeding material to a changing environment.

(viii) Participatory Plant Breeding

This method of breeding approach involves farmers and breeders. This method was outlined by Witcombe *et al.* in 1996. In this approach, the participation of both breeders and farmers is very important.

In this method, the breeders interact with the farmers and improve the locally adapted populations. The merits and demerits of this method are discussed below:

Merits

- Improvement of available local population.
- Breeding for specific adaptive traits.
- Also improvement of crop for resistance to endemic pests and diseases.
- Making the farmer available with improved populations of genetic stocks.

Demerits

- Only specific adapted populations with a narrow genetic base is available.
- Use of populations are limited due to geographical barriers.

6. Marker Assisted Backcross Method (MAS)

This method is used to transfer specific elite allele at a target locus from a donor line to a recipient line. The number of target genes involved in the selection and the expected level of line conversion must be defined.

Efficiency of MAS depends on the heritability of the target trait. DNA markers allow us to identify the allelic composition of genotypes in a segregating population. The main advantages of using DNA markers vs. conventional selection is to accelerate the fixation of recipient alleles at non-target regions and to identify the genotypes containing crossovers close to target genes. It is used in two ways, viz., (i) for complete line conversion, and (ii) partial line conversion as discussed below.

(i) Complete Line Conversion

The objective of a complete line conversion is to develop a line that will have exactly the same genetic composition as the recipient line, except at target loci where the presence of homozygous alleles from a donor line is desired. Such conversion requires strong selection pressure at non-target regions linked to the target gene (Tanksley *et. al.*, 1989). It is impossible to obtain complete line conversion, that is, the presence of only the homozygous donor alleles at the target gene. Therefore, line conversion is considered complete when, out of the selectable population, a genotype homozygous for recipient alleles at all detected non-target loci can be identified. The introgression can be completed in three to four generations for a single target gene, four to seven generations for three target genes, and four to nine generations for five genes, depending on the distance of flanking markers to the target gene.

(ii) Partial Line Conversion

The objective of a partial line conversion is to identify a line with donor alleles at target genes and a proportion of donor genome below a desired level. Usually no restriction would be enforced for the donor genome contribution outside the target loci over the genome. As the backcrossing continues, the ratio of the standard deviation to the mean of the donor genome contribution increases. This implies that the most efficient marker-assisted selection would be in later rather than early generations if only one generation of selection at non-targeted loci is applied. Without selection, the donor genome size in an individual decreases exponentially as the backcrossing proceeds, and most of the donor genome can be reduced through the Be process, especially on the non-carrier chromosomes. However, the difference between generations decreases with the number of genes included in the model. When more genes are involved in the selection model, the variation in the donor genome size is mostly from the non-carrier chromosomes.

7. Uses of Biotechnology in Genetic Enhancement

There are two main approaches in biotechnology which are used in pre-breeding viz., (i) genetic transformation and (ii) cell culture techniques. These are briefly discussed below:

(i) Genetic Transformation :

This technique involves transfer of alien genes without involving sexual process. It is a rapid method of pre-breeding by which various plant traits can be easily improved. Sometimes it takes long periods to bring transformed lines into desired levels of expression. The genetic transformation can be effectively used as a pre-breeding technique. The end product of pre-breeding can be used for developing productive cultivars and hybrids possessing novel genes.

(ii) Cell Culture Techniques

The somatic hybridization technique is useful in making new combinations of nuclear and cytoplasmic genes. It would be possible to enhance yield potential by selecting genotypes with balanced combinations of mitochondria, chloroplast and nuclear genes. However, at present, little is known about optimization of nuclear, mitochondrial, and chloroplastic combinations. DNA technology will help plant breeding in a more traditional way, when information is further developed on maps of restriction fragment length polymorphisms (RFLPs) and their linkages with useful traits in crop plants. *In vitro* tests, using RFLP markers, will allow near perfect accuracy in selecting for such useful linked traits. RFLP technology also will be used for precisely characterizing cultivars, gene frequencies of populations, and even to test hypotheses of land race evolution, and global movement of crop genotypes.

Perhaps, the greatest contribution of molecular biology to plant breeding will be a deeper and more precise understanding of gene action and inheritance, of cellular physiology and biochemistry, and perhaps of the whole plant physiology. With such deepened understanding, breeding and selection via standard sexual methods will be planned and executed with greater vision and economy. Such knowledge and execution will be, in part, a consequence of efforts to make genetic transformation a practical reality. The knowledge of genetic engineering if wisely utilized, will be of great benefit in practical breeding.

Thus, combination of various traits and introducing novel genes will result in a new emerging concept what is known as - Systems Thinking or Systems Biology. This is a consequence of genetic enhancement or pre-breeding.

8. Genetic Enhancement in Cotton

In cotton, pre-breeding programmes were carried out since early seventies in U.S.A., China, India, USSR, etc. Some examples of pre-breeding in cotton are cited below:

Development of Multiple Adversity Resistance in cotton resulted in the improvement of MAR-1 to MAR-6 gene pool especially for resistance to sucking pests, drought tolerance and improvement in fibre quality traits at Texas A & M University in U.S.A. The incorporation of G. *barbadense* into G. *hirsutum* and the interspecific diploid into tetraploid cottons have resulted in enhancing the level of gene expression. The Australian cotton industry are facing a major challenge from Fusarium wilt attack in G. *hirsutum*. It appears that their native species viz., G. *sturtianum* is immune to the *Fusarium* pathogen. However, the transfer of genes is quite difficult. Some progress is being made by using advanced approaches like chromosome doubling and embryo rescue. In India, lot of interspecific and intraspecific material has been generated in all the four cultivated *Gossypium* species. However, the extensive use of germplasm in crossing programmes has to gain momentum. This potential was realized with the available cotton genetic resources at Central Institute for Cotton Research (CICR), Nagpur. The work of prelbreeding or genetic enhancement has been initiated at CICR in 2002. Elite cultivars from all the three zones viz., North, Central and South have been taken up as base material and a crossing programme was initiated involving unadapted, unused G. *hirsutum* germplasm including wild species. In cotton, the genetic enhancement is required for various characters which are listed below:

(i) Yield

(ii) Fibre quality traits viz., fibre length, fibre strength and micronaire value

(iii) Seed Oil improvement

(iv) Resistance to biotic stresses

  a. Diseases like bacterial blight, CLCuV in G. *hirsutum*
  b. Tolerance / resistance to sucking pests and bollworm complex

(v) Resistance / tolerance to abiotic stresses

i. Drought

ii. Salinity

9. Achievements in Other Crops

Genetic enhancement programmes have been carried out in different field crops such as maize, barley, sugarcane, sorghum, potato etc. Some examples are cited below:

(i) Hierarchical Open ended Population Enrichment (HOPE) System

This system was first used by Kannenberg (1970) in maize. The main objectives of the HOPE system are (i) to provide a source of inbred lines that are genetically very different from those currently used in commercial breeding programmes, and (ii) the HOPE inbreds must be comparable in performance with current commercial inbreds both in *per se* performance and in hybrid combinations.

(ii) Recurrent Introgressive Population Enrichment (RIPE)

RIPE was first adopted in 1990 by D.E. Falk in barley involving male sterile facilitated recurrent selection. The system consisted of one set of three hierarchical levels which, like corn HOPE, was open-ended in that germplasm could move upward through the hierarchy and introductions could be added at the low level. However, the system was redesigned to intensify introgression at successive levels. The difference from HOPE system is that introduction must have some trait of proven merit. The methodology involves four sequential steps.

a. Selected lines are crossed with male sterile lines from the elite level to increase the amount of elite (E) germplasm through progressive backcrossing.
b. The base level is 50% E.
c. The intermediate level is 75% E
d. The high level is 87.5% E

and at 93.25% E, the selected lines are incorporated into the E level. This system increases genetic recombination to reduce undesirable linkages at each level and promotes lines with most desirable recombinants to the elite germplasm pool. At the E level, intermating and selection is done to improve the germplasm into unique and agronomically superior types. Thus, this system is useful in improving cross pollinated crops. It significantly diversifies the breeding value while still allowing the development of commercially competitive lines and cultivars.

(iii) Latin American Maize Programme (LAMP)

This programme was used in maize for broadening the genetic base in Latin America. The main objective was to assess the national germplasm and exchange of genetic resources in the region. The following steps were adopted:

i. Germplasm was tested for useful agronomic traits from sea level to 3300 m and from 41°N to 34°S across 32 locations in Phase I.

ii. The best selections of each country were tested across all locations in Phase III.

iii. These locations were clustered according to five homologous areas: lowland tropics, temperate.

iv. Selected accessions (268) were tested for their combining utility using a tester in atleast two locations within each region.

v. The best cross combinations (hybrids) and heterotic pools were obtained.

Thus, maize breeders now have access to the most promising stocks identified by LAMP to expand the genetic base in maize.

(iv) Breeding accomplishments in various crops

a. Sugarcane: Pre-breeding has resulted in development of inter-specific genetic stocks of S. *spontaneum*, S. *sinense* and S. o*fficinarum*.

b. Sorghum: Incorporation of *Ethiopian*, *Sudanese* land race traits into adapted Indian cultivars has been done. Genetic enhancement has also been achieved in cassava, oilseed, lentil, tomato, chickpea, groundnut, etc. In potato, genetic enhancement has been achieved through polyploidy breeding.

c. Potato: Culivated potato is a tetraploid species that was domesticated by ancient Peruvians in the Andes. There are many wild tuber-bearing *Solanum* species but only a few are cultivated. This wild and cultivated germplasm consists of diploid, triploid, tetraploid, pentaploid and hexaploid species. Some researchers have suggested that there is a narrow genetic base of cultivated potato in the northern hemisphere and hence germplasm enhancement methods were advocated to solve this problem. Thus, potato breeders developed day-long adapted populations derived from Andean tetraploid and diploid potato land races through mass selection. These day-long adapted tetraploid populations have been termed as Neo-tuberosum, and some potato breeders have incorporated this improved germplasm in their breeding programmes.

10. Advantages of Genetic enhancement

Genetic enhancement and plant breeding in the sense of final cultivar development can be used in two main ways: (i) in developing crops utilizing uncultivated and wild species, and (ii) in achieving further breakthrough in yield which has stagnated in many crops.

(i) Developing new crops:

This refers to (creating new crops where none existed before) development of advanced cultivars from landraces. Usually the advanced cultivars are used for industrial purposes and the landraces are used by farmers in some developing countries. Soybean and amaranth are often called as "new crops" in the United States, even though they were under cultivation for Centuries as landraces in China and in Central and South America.

The new product, when used in larger quantity, is improved in terms of oil percentage, grain storability, hardiness, texture etc. The rule is simple: the more successful the crop economically, the greater will be the demand and complaints about the same.

(ii) Achieving Breakthrough

This refers to changing old crops into new ones through the use of genetic engineering. Plants are considered to convert sunlight, air and water (and soil nutrients) into high value chemicals rather than commodity chemicals like corn starch or soybean oil.

Standard breeding approaches to modify chemical components have been used in Canada already, to make rapeseed into a new crop: "canola". Canola oil, unlike standard rapeseed oil, is essentially free of erucic acid and glucosinolates and therefore is safe for human consumption when used as a cooking oil. The starch producing gene (R gene), identified in pea, can be used for producing new kinds of special starches in old starch producing crops such as maize and wheat. In future, high value plant products will make intensive use of crop breeding to fetch higher or premium price in the market.

Thus, genetic enhancement through its base broadening approach in various crops will result in the large scale efficient use of all the three genepools in the development of superior cultivars.

The advent of genomic and computer technology has made it possible to unravel the real world of biology. The role of genomics and proteonomics are helping us to identify useful transgenic populations and develop novel traits in economically important crop plants. This will result in creating a broad base of genetic and phenotypic diversity. This science of system biology has increased the pace of genetic enhancement.

11. Problems associated with Genetic Enhancement

There are several problems that are associated with genetic enhancement programmes particularly when genes are introgressed from wild species. Some problems are listed below:

1. Cross incompatibility in inter-specific crosses.
2. Stability barriers and chromosome pairing in hybrids have restricted the access to genes from wild species into cultivated ones.
3. Linkage drag.
4. Hybrid inviability and sterility.
5. Small sample size of inter-specific hybrid population.
6. Restricted genetic recombination in the hybrid population.
7. Lack of availability of donors for specific traits viz. resistance to diseases, pests and bollworm.
8. Exchange and accessibility of cultivated species germplasm material has become difficult due to legal restrictions like IPR.

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