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Application of GRIiN for climate resilient variety improvement

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Abstract

In the nearly 12,000 years of history of domestication of plants global climate has changed, it is now changing and shall continue to change. Man, ecosystem, plants and crops have been responding to this change through their fitness and survival. Post industrialization change in human activity often accelerated climate change faster than the biological adjustment.This drag in fitness of crops due to climate change is a complex phenomenon and is difficult to address. Genetics of fitness, survival and adaptation in crop plants is a grey area of knowledge. By selecting for stable economic yield across environment plant breeders have overcome the impact of changing weather. Ecological genetics and plant breeding need to focus on better root and water usage efficiency. In this changing context genetic resources are to be seen with renewed interest. Emphasis should also be to collect and document ecotypes of a given specie/variety. These ecotypes may have morphological overlap but may express new traits under varying conditions.Thus, a large global Information base is to be created on ecotypes to simulate and design ideotypes that may perform under a bunch of stress conditions. Innovation centric research in the area of new biology with a focus onepigenetics, microbe - root interaction studies etc may open new knowledge and tools to handle climate change. The present division of crop science into separate silos is proving to be counterproductive and resists the application of GRIiN (Genetics, Resources, Information, Innovation and New Biology) to climate change. Tryst with climate change poses a new opportunity for plant breeders to organize themselves as an inter-science forum.

Key words: Ecotypes, epiallele, fitness, adaptation, GRIiN, climate change, endophytes, biodiversity

Ensure food for all

Setting aside the blame game of what derailed nature, India has to ensure legal access to its 1.2 Billion population. There are several ways to address climate change on agriculture and thus the food supply. Agricultural policy, changed agronomy, better crop husbandry, diversifying the food base and scaling up plant breeding are new options to mitigate the impact of climate. One way is to bring-in a better food security systemin a decentralized manner targeting the micro-land holders. The other approach is to increase production from the endowed areas, guarantee a minimum price for the produce, procure the surplus, and create a buffer for distribution in the food deficit areas. Since by Law access to food grain has been assured, it is necessary to produce/procure and store adequate food grain. This legal and moral binding of the Government transgress the condition imposed by climate change. By virtue of its mere size, elevation and soil variation climate change will have differing impact in different parts of the country. And it is in these context the impact of climate change on agricultural production is examined. We restrict this discussion to soil/climate drought and to high temperature stress on *Rabi*/*Kharif* season cereals.

What does production gain mean?

Prior to 1965 India produced a maximum of 12.0 millions of wheat per year. Subsequently, in 2013, wheat harvest alone touched 98 million tons of grain due tobetter use of inputs as fertilizers and water, superior crop husbandry practices, seeds of high yielding genetically superior varieties and the price that tilted towards the farmers. Area sown to cereals and other crops dramatically increased by replacing the less productive and non-remunerative dryland crops. Still, estimates show that cumulatively in the last 40 years India

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produced an additional 1,200 million tons of wheat. This volume of wheat would have otherwise been imported and would have cost the Government $(1200^{6} \text{ x } (2\text{x}10^{2}))$ US$.. Similarly one can calculate for all other crops like rice, cotton, sugarcane, mango, milk, egg, poultry fish and wood production etc. The contribution of agriculture research to the national well being cannot be merely equated with those who do research for getting some glossy publications. The very yardstick used to measure agriculture research should carefully account for the publications covering basic work, surveillance observations, trial and evaluations, social and economic sciences etc. Agriculture is an application of principles from different sciences and is not a homogenous subject to make a comparison as Garg and Kumar [1] have done. While doing so, they have done a great injustice to agriculture sciences and to 'Current Science". At a time when the ICAR system is batting against climate change such a comment creates bias against agriculture sciences.

Genetics in the context of climate change

Many species have shifted their phonology to survive under changing climate, mainly due to changes in ambient temperature. Plants abbreviated their growing season due to drought with a result on earlier onset of flowering stage. This seems to be one of the common drought escape mechanism that is stable and is herited in crop plants like *Brassica* spp., mustard [2].

Shuttle breeding

Early British researchers observed that the Indian Agriculture is a gamble against moisture availability. Soil and atmospheric drought were rated as major limitations. To breed varieties adapted to these harsh conditions shuttle breeding/generation advancement between contrasting widely separated locations was followed. Howard [3] grew during 1910 to 1915 wheat at Pusa, in Bihar (November to April), harvested it and grew the produce for selection and generation advancement in the dry desert tract of Quetta, Baluchistan (now in Pakistan, (Fig. 1). By doing so, he developed by 1915 some of the most adapted tall bred wheat varieties. The shuttle breeding experience of Howard was adapted by many researchers around the world to hasten the variety breeding efforts [4]. Exposure to contrasting environment, divergence and convergence of the material, field performance to biotic and abiotic stress permit the selection to be widely adapted.

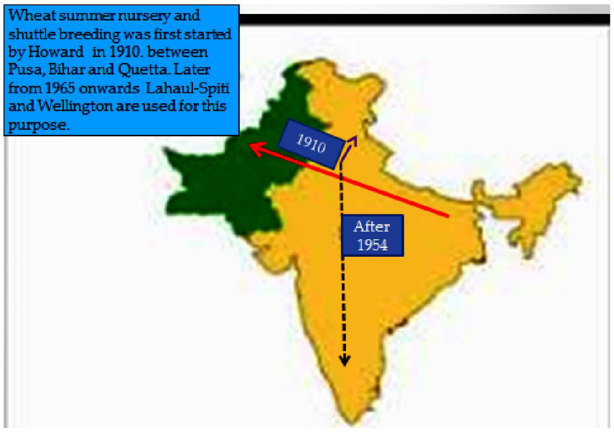


Fig. 1. Wheat summer Nursery was first raised by Howard at Quetta in 1910. Since 1964 Wellington in south India and Lahul Spiti in Himachal Pradesh are being regularly used by the Indian wheat programme

Narrow base

The annual report of the Project Director (Wheat) [5, 6] reveals that Kauz, Atilla, Veery, Seri and such bio-similars dominate the varietal development in India In other words for almost past twenty five years, morphologically differing but genetically overlapping varieties have been released for cultivation by the AICWIP. This genetic vulnerability has made our crop improvement programme prone to climatic aberrations. Further the seed production data of the AICWIP indicates (6) that maximum seed production is that of Lok-1, GW322, GW273, MP1544 and several wheat varieties of Gujarat and Madhya Pradesh released several decades ago. Of late, the genetic gain if any made by the wheat breeding programme, has not reached the wheat farmers of Central Zone (CZ).

Some of the CZ varieties like Lok 1 with good chapatti quality (known as "lokvan" by farmers is under cultivation for the last 30 years in the water deficit, warmer CZ) possibly has several ecotypes within it. Similarly, the TMV2 ground nut, sugarcane variety Co440, dusheree mango etc. cultivated for almost five decades and over large area may possess ecotypes within them. These variety ecotypes need to be collected and documented, by the NBPGR to mitigate climate change. India's plant genetic resources, mainly the ecotypes should be made accessible by the crop improvement programme. These original varieties that have become a matter of common knowledge; but the ecotypes adapted to specific local weather pattern. In all likelihood, would fall under the biological diversity

[7] and should be entered in the biodiversity register maintained by the panchayat. To collected, documented, share and use these ecotype in crop improvement programme approval from the state and central systems may be necessary. These ecotypes are different from farmer's variety [8] and are product of the plant-environment interactions (Fig. 2).

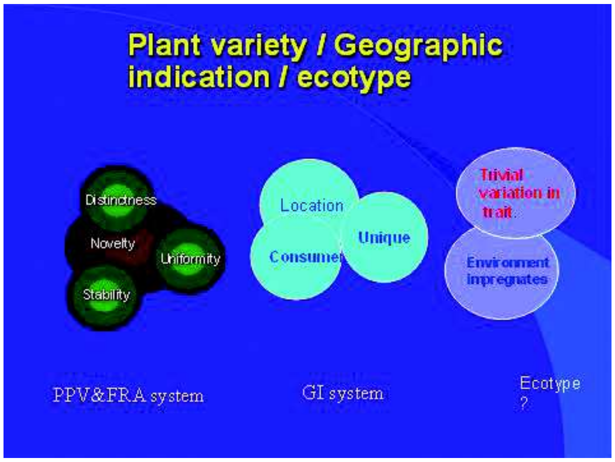


Fig. 2. Comparison between Plant Variety, GI system and ecotypes

Root type

In wheat, based on field measurements supported by laboratory experiments three major root pattern have been identified (9. as various clusters. Cluster 1, type of plants hasboth surface and deep roots, with capacity to extract maximum water for the root biomass invested by the plant. Such ideotype are taller with excellent root anchorage and the energy demand of the plant/root reduces the yield. The other extreme is cluster 3, with shallow, surface feeder roots with poor root structure. These poor soil moisture extracting plant types yield less and are prone to heat and drought stress. Cluster 2, which for all practical purposes an intermediate root type having a judicious blend of deep and surface roots is the most moisture/stress efficient ideotype with very good yielding capacity under varied conditions.

Genetic resources

Plant germplasm collections are important repositories of genes that ensure potentially useful sources of genetic variation are preserved for future uses. Detailed information about genetic differences among individuals or groups of accessions can be helpful for management and utilization of germplasm collections. Presently, a sketchy information is collected of the site is required and there is a need for a standardized site details collection format to cover a) ecological features of the collection site and b) a method to retro-classify poorly documented accessions site. Such detailed eco-classification will add precision for the usage of specific trait/germplasm.

Innovating new procedures and methodologies, finding new uses for known instruments are essential to confirm novel traits in the germplasm. A screening and selecting strategy was innovated that has relevance to climate change induce high temperature regimes at the time of flowering. Using high glasshouse and field temperature conditions (within in canopy and above ambient temperatures) a mutant of N22 rice type was identified that was little tall, more heat tolerant to temperature, early to flower and with less tillers. This new resource innovated for high temperature tolerance can be a very useful material in breeding for climate change [10]. High temperatures interact with the plant in several ways. The shortened flowering time is an escape mechanism against high temperature. The changed plant phenology provides another platform to out-smart climate change. New ideotype capable of improved light conversion, longer grain filling duration and higher harvest index or genotypes that tolerate > 30^{0}C at anthesis time, producing more grain and bolder per head are likely to be climate tolerant.

Role of fitness ad survival

Physiological reasoning for yield associated with dwarfing genes in cereals hints of a trade-off between stem growth and grain set [11]. In cotton (*Gossypium hirsutum*) and tomato (*Solanum lycopersicum*) the competition for resources between vegetative and reproductive growth is expressed by the determinate stem growth pattern, early senescence due to heavy bearing and the competition for resources by different plant parts. As the plant grows there seems to be conflict between plant parts for sharing resources as one plant part saps the energy and dominate over the rest of the plant. In breeding for climate resilient plant type innovating appropriate crop design with minimum energy conflict between plants partis strive to be achieved.

The observed change during the last half a century due to climate change is the altered seasonal weather pattern. Unpredictable long and dry summer occurring in successive annual cycles, late/extended winter, severe second half of the NW monsoon, etc are becoming more common. These weather patterns disturb the distribution and abundance of species. To cite an example, Insects have short life span, can quickly become abundant and are one of the most widely adapted living organisms. Therefore, several researchers have [12, 13] investigated the insect specie's thermal performance curve (TPC) and modeled the unifying response behind climate change. The tropical biological systems under TPC tend to move towards fitness. Increased fitness at higher latitudes becomes a challenge due to wide within year thermal variations. Insects seem to enter diapauses to escape negative fitness (latency in plant pathogen) when high environmental temperatures prevail. Many tropical ecotherms have decreased fitness due to climate change. What sort of impact it will have on the productivity in the man-made agricultural systems is still being debated as even occasional spells of heat wave seem to affect their fitness.

What genetic resources are needed?

Ecological races and species are commonly called as ecotypes. A multitude of ecological races have arisen due to natural selection under different environmental conditions mainly due to latitude and altitude variations. Natural ecosystems adapt to abiotic stress by forming symbiotic associations with Class 2 fungal endophytes. Without the endophytes, plants are not stress-tolerant and do not survive in the habitats to which they are adapted. Symbiotically conferred stress tolerance typically occurs in a habitat-specific manner and is based on interactions between environmental factors on both plant and fungal genomes. The endophytes from geothermal plants confer heat tolerance, and endophytes from coastal plants confer salt tolerance. This habitat-adapted symbiosis increases the plant growth and development while decreasing water usage [14]. Though endophytes have no effect on photosynthetic rate and metabolic efficiency they significantly increase the photosynthetic efficiency. Endophytes alter the ratio of up regulated to down regulated (UR: DR genes) plant genes compared with non-symbiotic plants. Specific UR: DR gene ratios vary with the endophyte species and the habitat [14].

Ecotypes and epigenetics

The dictionary meaning of "Ecotype" is a group of organisms within a species that is adapted to particular environmental conditions and therefore exhibits behavioral, structural, or physiological differences from other members of the specie. Ecotypes seem to vary conspicuously for fitness and survival under climate change situations. In Norway spruce trees were selected with established pedigrees and were grafted and planted in southern Norway locations rather than at the source area in northern Norway from where the materials originated. When the grafted trees produced seeds they were planted back at their original northern sites. Plants from these seeds resembled the tree populations growing in the southern states than their kin in the northern part of the country. The growth rhythms of the seed from this new southern orchard were more in tune with the day lengths and temperatures of the southern environment. In fact, the seed from this southern orchard were not suitable for the northern part of Norway. As the climate changes, developing seeds receive environmental clues that allow them to make adjustments to improve their ability to grow in a novel climate [15] (Fig. 3). The edaphic factors seem to significantly alter the morpho-physiology of the progeny as the widely varying annual climate rhythm shall make plant breeding and selection more difficult.

Heterosis, or hybrid vigor, is widely exploited in agriculture;yet a complete description of its molecular basis has remained elusive despite extensive investigation. It appears that there is not a single, simple explanation for heterosis. Instead, it is likely that heterosis arises in crosses between genetically distinct individuals as a result of a diversity of mechanisms. Heterosis generally results from the action of multiple loci, and different loci affect heterosis for different traits and in different hybrids. Hence, multigene models are likely to prove most informative for understanding heterosis. Complementation of allelic variation, as well as complementation of variation in gene content and gene expression patterns, is likely to be an important contributor to heterosis. Hybrid vigour has been

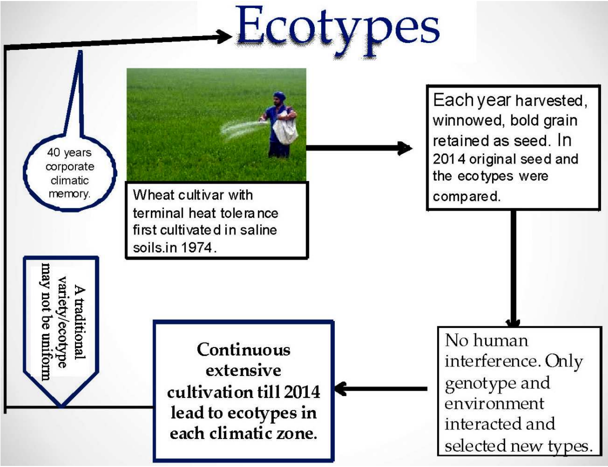
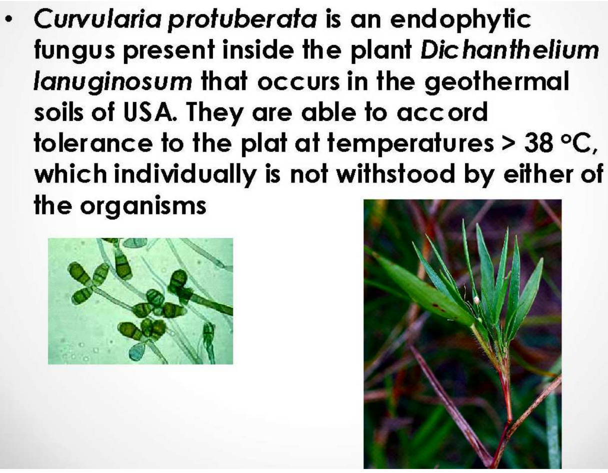


Fig. 3. Ecotypes and how they emerge

attributed to the non-additive accumulation of sRNA which in turn can influence the DNA methylation and the gene expression leading to hybrid vigour [16]. This new knowledge has the potential to rewrite some of the basic concepts on heterosis.

There are numerous reports of fungal symbionts conferring tolerance to moisture stress, heat tolerance, and salt tolerance etc, to the plants they harbor. For example *Curvularia protuberata* is an endophyte fungus present inside the plant *Dichanthelium lanuginosum* present in the geothermal soils of USA is able to accord tolerance to the plat at temperatures > 38 ^{o}C, which individually is not withstood by either of the organisms [17] (Fig. 4). In barley most of the endophytes like the

Piriformospora indica confer resistance by different mechanisms and the resistance accorded seems to be systemic. Single seed descendants of "McKenzie" wheat variety tolerant to *Fusarium* Head Blight, became resistant when the wheat streak mosaic virus infected this single stranded RNA like virus rendering the host more tolerant to the virus disease and the fungal pathogen. The WSMV is mite transmitted [18, 19] The potential of using the 9,384 base pair plant RNA viruses called wheat streak mosaic virus as a mediator and molecular tool in crop improvement has opened new opportunities in epigenetics and in transgenic development.. These systemic plants sRNA is capable of "gene expression alteration" and in enhancing the FHB resistance in wheat without the assistance of an active crossing programme.



- ***Curvularia protuberata*** **is an endophytic fungus present inside the plant** ***Dichanthelium lanuginosum*** **that occurs in the geothermal soils of USA. They are able to accord tolerance to the plat at temperatures > 38 °C, which individually is not withstood by either of the organisms**

Fig. 4. Epigenetics – when both *Curvularia* spp and endophyte *Dichanthelium* spp. occur together then temperatures above 38^{o}C is tolerated, not when present alone

Information and innovation

Epigenetics works alongside natural selection to provide an additional mechanism for trees, and other organisms, to adapt to their environment. At some point, climatic conditions may change too drastically for even epigenetics to overcome. Epigenetic changes might also contribute to the ability of plants to colonize or persist in variable environments [20] and the role of environment on epigenetic marks has been reviewed [21].

The endophyte fungus SMCD 2206 colonizes wheat root and improves wheat tolerance for drought. Methyl-sensitive amplified polymorphism (MSAP) indicates epigenetic modifications in drought-stressed wheat. The DNA methylation patterns observed in drought-stressed wheat seedlings co-cultured with SMCD 2206 resembled those of unstressed controls (with or without the endophyte) much more closely than those of endophyte-free, drought-stressed plants. Consistent with the documented roles of transposable elements in plant epigenetics, DNA sequences isolated from some of the most prominent polymorphic MSAP bands were similar to a CACTA type transposon [22]. These findings give a clue on the mechanisms involved in plant–endophyte colonization of wheat coinciding with epigenetic differences in the plant host to drought stress.

The infidelity of replication of methylation patterns has the capacity to generate heritable phenotypic diversity among genetically identical cells. Mangroves (*Laguncularia racemosa*) trees of the coastal-marine ecosystem and is widely distributed from tropical to mid-latitude brackish water bodies and lagoons. The tree varies considerably for leaf shape and other morphological features though they are genetically comparable populations. Despite morphological dissimilarities of mangroves from the salt loaded coastal marsh to fresh water riverside collections present abundant DNA methylation differentiation suggesting epigenetic variation in natural populations helping individuals cope with different environments [23]. May be, the perennials mine the epigenetic alleles to survive under widely varying year to year environmental variations with maximum fitness.

Perennials are classic epigenetic cases

Effect of increased winter temperature in higher latitudes varies widely making predictions difficult. Heat-tolerant apple trees are suitable for growing in warmer climates with moderate winters and extreme summers. The Stark Brothers Nurseries and Orchard Company in Montana, USA is in business since 1815. They discovered the Cinnamon Spice apple in California and the Granny Smith apple from Australia that are heat tolerant. Perennial trees like popular can be clonally propagated by ramets and provide an opportunity to plant same clone/ramet at widely separated locations for examining epigenetic impacts .Raj *et al*., [24] noted transcript abundance pattern based on geographic origin of where the ramet was planted. Epigenetic based transcriptome divergence was noted depending on how long the ramet was in a given location. Mild phenotypic variation created by epiallele may not drastically alter fitness and yet provide resilience against climate change. Thus epigenetics and adaptation studies are potential plant breeding platform to breed climate responsive varieties

Summary

Over millions of years plants have evolved different pathways of adaptation to enable their dispersal, migration and fitness and survival. The four groups such as the trees, perennial grasses, annuals and the microbes have put in place complex infer dependent systems, heritable host traits, trait trigger/silencers and functional alleles outside the cell. In response the host has put in place ecotypes of plants to respond to the local physical environment. Poly embryony, intra plant competition and alternate physiological pathways have been kept ready for climatic exigency. Therefore, to develop climate resilient crop varieties programme GRIiN (Genetics, Resources, Information, Innovation and New Biology) must be created within the plant breeding departments to put in place a dynamic onward looking variety development programme.

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