Invited Paper

Biodiversity, Climate Change and Homeostasis in Crop Improvement

M.P. Dhanapala*

Former Director, Rice Research and Development, Department of Agriculture, Peradeniya, Sri Lanka

**Corresponding author: maddumadhanapala@yahoo.com*

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Abstract

Biodiversity confers buffering capacity or homeostasis to living organisms and helps their survival under stress conditions of the environment. In agricultural crops, open pollinated species in particular, biodiversity declined with domestication and subsequent genetic improvement; the land races, open pollinated populations, composites, synthetics, clones, hybrids and inbred lines/pure-lines are plant breeding end products in the order of declining biodiversity while assuming homogeneity within populations.

In rice, significant decline of biodiversity by genetic erosion is noticed with the restriction of many traditional land races/varieties to a few pure-lines in 1940s; a few old improved varieties in 1960s and limited use of germplasm since 1970s to develop new improved varieties. Loss of biodiversity is irreversible but options such as varietal mixtures, advance bulk populations with little or no selection etc. are available to simulate biodiversity and thereby introduce homeostasis. However, the modern rice cultivars with proven stability and adaptability to a wide range of environments have inbuilt homeostasis or buffering capacity, even as homogeneous populations, because of rigorous screening in different agro-ecological environments before being recommended for cultivation.

The climate change signified by erratic rainfall and elevated temperatures at present cannot be considered alarming for rice cultivation in the country. The rainfall pattern and temperature fluctuations need to be monitored, if necessary, to redefine the rice cultivation seasons. The modern rice varieties posses the resilience needed to contain climate changes experienced today. They are photo-insensitive, period-fixed types with a growth duration range of 75 to 120 days, and can be grown year-round. They can fit into any cultivation period dictated by the climatic parameters.

In addition, the cropping system information may help sustain productivity in rice-based farming. However, the new technologies generated to mitigate climate change have to be appropriate for the farming community.

Keywords: Biodiversity, Buffering capacity Climate change, Genetic erosion, Homeostasis

Introduction

Biodiversity and climate change are key words appear frequently in agro-ecological symposia at present. The term 'homeostasis' refers to the buffering nature conferred by the genetic heterogeneity within populations to the environmental stresses. Homeostasis is regarded as a function of biodiversity within populations.

Biodiversity in agricultural crops declined gradually in the process of crop-improvement since domestication. With the advances made in genetics and plant breeding, the consequences of biodiversity decline were felt in the agricultural sector. The recent changes in climatic parameters as a result of deforestation, greenhouse effect, air pollution from industrial and vehicular emissions intensified the need to reconsider biodiversity and homeostasis to introduce climatic resilience and improve the capacity of crops to buffer the changes in the environment.

Biodiversity in general

Biodiversity is interesting. In a hypothetical situation of human beings with no biodiversity, ignoring the sex differences etc., all the individuals have to be a replica of someone in its cell lineage and would be identical, genetically and otherwise. If the ancestor is Hitler, then, all would be Hitlers; if Einstein, all would be Einsteins. Under such circumstances if all ladies descend from Cleopatra, it would be difficult to choose your partner. To be more precise, you need not select then; anyone would be the same Cleopatra provided she fits into the age group you look for. The danger with no biodiversity is that all would succumb to any disastrous situation specific to that community, sparing no one to continue the generation.

Human beings apparently retain the highest degree of biodiversity as they were the least subjected to selection. As human-beings we all appear alike, but not identical. Despite the fact that we all are humans, each one of us differ genetically from the rest of the population, the reason behind legal acceptance of DNA polymorphism. Children differ from their parents even though they share all of their genes from parents. You are different from your own brother/sister unless he/she is an identical twin of yours. As humans, each of us represents only a specific gene assortment from the vast human gene pool on earth. Accordingly, the gene pool conferring biodiversity persists through generations, if undisturbed.

Open pollinated crops and homeostasis

The individuals within populations of open pollinated crop species are diverse, heterogeneous and differ genetically in many traits. Some gene loci may be heterozygous too. As populations, they are tolerant to environmental stresses. Some individuals in the populations could have the potential to withstand and survive specific stress condition while some gets eliminated; the gene frequencies of the resultant population get adjusted accordingly in the generations to follow. This phenomenon, the capacity to buffer stresses, is referred to as homeostasis. However, the genetic improvement process based on advance technologies eroded the genetic base while disturbing homeostasis at species level. For example, the inbred lines develop by enforced inbreeding make them homozygous and homogeneous. Hybrids are developed by crossing two inbred lines; the resultant progeny (F_1), though heterozygous predominantly, is homogeneous and consists of genetically identical individuals. The clones developed by vegetative propagation (cutting, grafting etc.) are homogeneous as the individuals carry identical genetic information of the mother plant. The tissue culture based propagules too are genetically identical and inherit exact genetic information of the mother tissue unless there had been somaclonal mutations in the culture media used for callus induction and plant regeneration. Synthetics are populations developed by inter-crossing few inbred-lines of superior general combining ability (GCA) and are maintained similar to open pollinated populations. Their variability is limited to the genetic constitution or diversity of the inbred-lines involved. Even in open pollinated populations (OPP), including composites, the intensity of selection in the improvement and maintenance of populations narrows down the genetic base thus affecting homeostasis. This may sometimes leads to inbreeding depression and degeneration of such populations at high intensity of selection.

Biodiversity and genetic erosion in rice

The self-pollinated crop populations (obligate in-breeders) like rice and wheat are naturally less variable. Illefe (1922), a British scientist who initiated pure-line selection from traditional rice varieties in Ceylon described that the traditional varieties maintained by farmers were as mixtures (land-races) of different types. It is evident, therefore, that genetic diversity existed even within cultivars of in-breeders due to undetected or rather ignored physical and genetical mixing. The heterogeneity within and among the land-races may have conferred some degree of homeostasis to the traditional rice varieties in the country. However, the different types within land-races are homozygous, pure breeding genetic entities. Any plant isolated from such a population would produce a progeny similar to the mother plant. This is the basis of pure-line selection of traditional rice varieties performed in Ceylon since 1920s. Selection and recommendation of few pure-lines (21 pure-lines) from a large number of traditional varieties (≈700 varieties, Molegoda (1924), Soyza (1944), exact number is not known) set-in the first round of genetic erosion in rice. This was further aggravated by the development and recommendation of few old-improved varieties (OIVs) (8 'H' varieties). The semi-dwarf new improved varieties (NIVs) developed since 1970s further restricted the use of rice germplasm to a few parental varieties in the transfer of yield determining traits. In most instances, the semi-dwarf parent was used as the female parent of crosses, for convenience of detecting self-pollinated plants, thus narrowing down the cytoplasmic genome too. The target then was self-sufficiency and food security.

Consequences of genetic erosion

Biodiversity results from the accumulation of gene mutations and the genetic recombinations in nature for millions of years. Genetic erosion narrows down this genetic base and leads to homogeneity within crop species thus affecting homeostasis and making them vulnerable to environmental (biotic and abiotic) stresses. The classical example of this nature is the extensive use of the Texas Cytoplasm (T-cytoplasm) to introduce male sterility in hybrid corn in the United States of America (USA). The T-cytoplasm itself carried the gene/s for resistance to Southern Corn Blight (*Helminthosporium maydis*). A virulent mutant of the pathogenic fungus destroyed the all cultivated corn hybrids of T-cytoplasm-origin in 1970s. Coffee rust in Ceylon and potato famine in Ireland may be considered as similar situations; we need biodiversity to contain epidemics of this nature. Genetic erosion is, therefore, disastrous, irreversible and the original status cannot be re-established. This makes biodiversity indispensable.

It is important to note that over 1200 rice varieties, including the traditional varieties, are conserved in the Plant Genetic Resource Center at Gannoruwa, Peradeniya. The world rice collection at the International Rice Research Institute, Philippines constitutes around hundred thousand accessions. Among them are rice varieties grown globally in different altitudes from 40° N to 40° S. Access to this germplasm is available for rice scientists.

Climate change and its consequences

The potential of any cultivar is determined by the Genotype × Environment (G × E) interaction. Climate is a key component of the crop environment. The major climatic factors are rainfall (amount, intensity and distribution), temperature (average, maximum, minimum), humidity, solar radiation (intensity, duration), and wind (velocity, direction).

If the earth is not tilted by 23.44° from its perpendicular position, as a result of celestial forces acting on it while revolving round its own axis (once a day) and orbiting round the sun (once a year), we may not have had the glacier caps in the North and South poles, no clear cut seasons as Winter, Summer etc., no long and short days; the net result would be disastrous, possibly elevated mean sea level (MSL) and the same climate all over the world with 12 hour day and 12 hour night similar to that in countries around the equator (Java, Ecuador and some parts of Brazil). Relative to the above situation, the global warming and erratic rainfall experienced today are non-significant issues that can be contained by appropriate actions (reforestation, emission control etc.).

Crops are vulnerable to changes in the climate especially when the biodiversity is eroded. The rice crop encounters sterility if the minimum temperature drops below 20 °C or maximum temperature exceeds 38 °C during the critical stages of the reproductive phase. Some cultivars are more sensitive to temperature extremes than others. It is interesting to note that male gametes are more sensitive to temperature changes. This factor is used to induce thermo-sensitive male sterility in hybrid rice research.

Homeostasis, a mitigating option for climate change

Simmonds (1979) discussed the importance of heterogeneity, heterozygosity and stability in crops in relation to homeostasis or buffering capacity to the environmental stresses. Heterozygosity leads to heterogeneity and biodiversity of crops at species level. Although hybrids exploit heterosis/heterozygosity for its yield advantage, the individual plants within hybrid populations (F_1) are genetically uniform, homogeneous and non-homeostatic. However, the hybrids are reportedly more stable and adaptable to environmental changes than the parental varieties used in hybridization. Rice being an obligate in-breeder, exploitation of heterosis/heterozygosity to introduce homeostasis is limited.

The possibility of releasing advance bulk populations (F_7, F_8), eventually subjected to natural selection only, to introduce homeostasis at population level is suggested for in-breeders (Simmonds, 1979). The parental varieties for this purpose need to be selected specifically, considering the genetical distance between them, to suit the consumer preference.

Heterogeneity of the rice crop at population level can be introduced by mixing carefully selected compatible varieties (genotypes) for age, grain type, pericarp color and plant architecture to suit consumer acceptance. Evidently, the yield level experienced from such mixtures surpasses the weighted yield average of the individual constituents of the mixture. This is a fact to be verified before making recommendations. Continuous cultivation of varietal mixtures may lead to domination of one or two varieties in the lapse of few generations (Simmonds, 1979). Varietal mixtures in in-breeders, and composites, synthetics and OPPs in out-breeders are in this category of plant populations; this process indirectly simulates the land races in the past.

The modern rice cultivars are extensively tested for adaptability and stability, either with regression model (Eberhart and Russell, 1966) or with variance component model (Abeysiriwardena et al., 1991), prior to the recommendation for cultivation; they are proven stable over a range of environments and have inbuilt capacity or homeostasis to buffer the changes in the environment as individual genotypes or as homogeneous populations. Hopefully, they have adaptability to the present level of changes in the climate.

The erratic rainfall and slightly elevated temperatures observed presently cannot be considered alarming for the modern rice cultivars and the best option would be to examine the climatic factors very carefully and re-establish the cultivation seasons to suit rice cropping. Day length is the most consistent climatic parameter and can be used as a guideline to fix cultivation seasons for rice. The erratic rainfall and temperature fluctuation need to be monitored, if necessary, to redefine the rice cultivation seasons.

The majority of modern rice cultivars are photo-insensitive, period-fixed types. Those can be cultivated year round if the seasons are determined. There are different maturity groups, range within 75 - 120 days, to select among the cultivars to fit into any cultivation period dictated by the climatic parameters. Some rice-based farming and cropping systems: mixed cropping, multiple cropping, relay cropping, catch cropping etc., may also help to minimize the effects of climate change and sustain agricultural productivity. However, some of these strategies are considered primitive in the context of modern agriculture. In future-strategies of rice improvement, climate resilience of cultivars needs to be given priority considering the facts on homeostasis. It is always important to deliver the most appropriate, feasible and economically viable, technology to the farmer.

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