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Genetic Parameters and Selection Strategies to Identify Climate Smart Wheat

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The nature and magnitude of genetic parameters like components of genetic variance (additive, dominance and epistatic), coefficient of variation, heritability and genetic advance may vary from character to character for the same population, population to population for the same character and environment to environment for the same population and same character. An abiotic stress may be the major cause of such variations. The magnitude of such variation may be relatively much more if there is simultaneous occurrence of two or more abiotic stresses such as drought, salt and heat stress coupled with high seasonal and interannual variability of the environment. High temperature affects wheat crop yield by affecting in different ways including poor germination, reduced photosynthesis, increased leaf senescence and decreased pollen viability, which leads to production of reduced number of effective tillers, number of spikelets per spike, less grains per ear and smaller grain size and consequently, reduction in overall productivity.

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1. INTRODUCTION

Wheat supplied with ample doses of fertilizers produced significantly lesser straw and grain yield, particularly due to severe reduction in direct or indirect traits like number of spikes per plant under higher CO_2 (700 ppm) and temperature (30°C) conditions [1]. Similarly, Singh et al. [2] emphasized that continual heat stress is a problem in about 7.0 mha area, while terminal heat stress is a problem in about 40% of the irrigated wheat growing areas throughout the globe. Many workers have observed in their studies carried out in different years that additive genetic component and unfixable epistasis responded more to change in environmental conditions than the dominance component and fixable epistasis, indicating that heterozygotes exhibited higher stability than the corresponding homozygotes, *i.e.,* superiority of hybrids. Since the development of hybrid wheat varieties has not so far being successful at commercial scale, the best way to increase the magnitude of dominance variation in wheat is to increase magnitude of homozygous genomic heterosis (intergenomic heterozygosity) by utilizing alien gene transfer, *i.e.,* 1B/1R, 7D/7Ae, *etc*. The stress affects the means adversely, causes reduction in both genotypic and phenotypic variances but increases heritability in many cases. Degree of dominance does not vary too much between the environments, that is why, the yield of cereals is stressed in dry land areas, which increased only modestly as compared to irrigated areas. The estimation of genetic parameter should be done under the environmental conditions where selection is to be practiced. This paper briefly emphasized the impact of environmental conditions on character expression, genetic parameters and selection strategies for developing elite germplasm lines and/or improved climate adaptive wheat varieties.

2. TARGET ENVIRONMENT AND BREEDING STRATEGY

Since yield is the integrated product of genotypic expression in a given environment, the production potential of the target environmental conditions can affect the decision regarding breeding strategies. Therefore, one important question arises that whether the breeding for the target environmental conditions should rely on selection under favourable conditions and subsequent testing of selected material in target environmental conditions or on direct selection under target environment, or stated differently, whether the estimates of genetic parameters, which determine the kind of selection procedure to be adopted to maximize improvement, should be obtained from target or favourable environment?

Temperature exposures above 30°C are associated with large wheat yield reductions and contribute substantially to overall negative warming impacts. Falconer [3] emphasized that the genotypes selected under favourable environmental conditions though showed their superiority over the genotypes selected under unfavourable environmental conditions when grown under good crop growing conditions. The situation was just reverse when they were grown under poor crop growing conditions, *i.e.,* the genotypes performed better in the environment, under which, they were selected, while discussing barley and wheat improvement for moisture-limiting area in West Asia and North Africa. If the yield production potential of the target environmental conditions is high (30 q/ha and above), selection should effectively be practiced under favourable crop-growing conditions [4]. However, if the yield potential is low (below 30 q/h), it would be more efficient to select plants directly under target environment. The estimation of genetic parameters should therefore be done under the environmental conditions where selection is to be practiced.

The view of Srivastava (1987) seems to be justified because the lines selected under favourable conditions will generally be different from those selected under unfavourable conditions, *i.e.*, selection for high yield potential under good crop-growing conditions does not generally cause a carry-over effect under stress environmental conditions (Table 1). Similarly, direct selection under stress environments will reduce yield under favourable environments unless genetic variances in unfavourable environmental conditions considerably greater than those under favourable environmental conditions, and genetic correlations are positive and close to unity.

Another basis for direct selection for yield potential under target environmental conditions is provided by the fact that general adaptation to a wide rangeof environments representing different

Table 1. Mean yield performance (q/ha) of wheat varieties tested under two different environmental conditions over different locations during 2008 and 2009

Variety	Restricted irrigated conditions	Rank	Rainfed conditions	Rank
WH 1080	34.9	3	32.2	1
HD 3013	33.5	8	32.0	2
PBW 613	32.4	11	31.7	3
WAS 315	34.1	6	31.3	4
WH 1081	35.6	1	30.8	5
C 306#	26.4	13	28.7	12
PBW 175#	35.1	2	29.9	8
CD (0.05%)	2.2	-	1.1	-

stresses may cost the genotype some yield sacrifice. It is therefore, better to evolve separate varieties with best fitness in separate small areas, *i.e.*, sacrificing some wide adaptability in favour of specific adaptation to cope with prevailing stresses that limit yield and stability of production. For marking a breeding programme more effective to evolve elite germplasm particularly for poor environments (production, potential below 30 q/h), varieties should be developed to meet the specific needs of a particular area.

3. MEAN VALUE AND GENETIC PARAMETERS

Several studies have been carried out to know the effect of change in environmental conditions on the magnitude of various genetic parameters. The estimate of mean, coefficient of variation, heritability and genetic advance for seven metric traits in parents, F_1 and F_2 generations of a 9 x 9 wheat diallel grown under irrigated (normal) and rainfed (stress) conditions were studied and noted significantly higher mean values for all the characters under normal environmental conditions than under stress conditions except 1000-grain weight. On contrary, both genotypic and phenotypic coefficients of variation were higher in stress environmental conditions for all the traits. Similarly, the estimates of heritability in majority of the cases were higher under stress than under normal environmental conditions, whereas, the genetic advance was higher in stress environmental conditions for days to heading, 1000-grain weight (g), Just an antagonistic condition was found for plant height (cm), total biomass, grain yield per plant and tillers per plant, *i.e.*, their values were more under normal than under stress environmental conditions. These results clearly reveal that 1000-grain weight (g) improved under stress environmental conditions [5].

Dhanda and Sethi [6] studied genetics of yield and its related traits in nine generations (P_1, P_2, F_1, F_2, F_2, F_3, F_3, B_1, B_2, B_1s and B_2s) under irrigated and rainfed conditions in wheat cross CPAN 1992 x Kharchia 65. The mean performance of all the characters was considerably lower under rainfed conditions than under irrigated conditions. Although both the additive and dominance components were involved in the expression of all the traits under both the environments, yet the dominance component, in general, suffered more than the additive component under rainfed conditions. Additive component appeared to be main source of genetic variation under both the environments. The estimates of heritability and genetic advance were higher under irrigated than under rainfed conditions, which might be due to better expression of genotypes under normal conditions.

Singh et al. [7] determined photothermal response by raising 50 genotypes of wheat under four photothermal environments created through alteration of sowing dates from October through December. By taking days to heading as the key diagnostic character for photothermal response, they classified the genotypes into five groups-photoperiod non-responsive and high temperature sensitive. photoperiod non-responsive and low temperature responsive, photo-thermo sensitive, partial photothermo-responsive, and photo-thermo insensitive and computed groupwise phenotypic and genotypic correlation coefficients. Grain yield showed positive correlation with grain weight, grain number and tillers per plant in all the photothermal environments and negative correlation with days to heading, maturity and flag leaf duration in E1 and E3 environments (sowing dates, 5th October and 5th December, respectively). In general, the magnitude and direction of correlation changed with a change in photothermal environment.

Noori and Sokhankhanz [8] studied Triple Test Cross Analysis for Genetic Components of salinity and tolerance in spring wheat. The data obtained from 75 families produced by crossing 25 F_2 plants derived from a cross between two spring hexaploid wheats, namely Siete Cerros (salt tolerant) and Axona (salt sensitive), to their parents and their F_1 progenies were subjected to triple test cross analysis. The genetic components (epistasis, additive and dominance) and their interactions with the environmental conditions (control- salinity) were detected for heading date, days to maturity, final plant height, spike length, ear weight, straw weight, number of grains per ear, grain yield per plant, 1000 grain weight, whole plant weight and harvest index. Epistasis was presented only for days to maturity ('j' and 'l' types) and plant height ('i' type) at control and spike length ('j' and 'l' types) under salinity conditions. Additive component (D) was more important than dominance (H) especially under salinity conditions. This and a subsequent study conducted by Singh et al. (1991) led the authors to conclude that the estimation of gene effects should be carried in wide range of environments [9]. A similar study conducted by Redhu et al. [10] to quantify various gene effects in three wheat crosses (Kharchia 65 × WH 157, Kharchia 65 × WH 283 and HD 2009 × WH 283) grown under normal *vis-a-vis* saline environment, indicated differential genetic mechanism under two environmental conditions for all the three crosses in respect of the adequacy of model, the nature, magnitude and the level of significance of gene effects for yield and its component traits, Also, the duplicate type of epistasis was more pronounced under normal than under saline environmental conditions, however, the saline soil was typically patchy in their salinity. The yields of crops growing on them are similarly patchy. But, since most of the yield from such fields comes from least saline areas, the best strategy for maximizing overall yield is to select for high yield on non-saline soils.

Mohsin et al. [11] also evaluated genetic variability for quantitative traits and found characters like biomass, number of spikes, spike length, grain for spike, 1000-grain weight and harvest index of utmost importance, which may be used as suitable selection criteria in wheat breeding.

4. TRIPLE TEST CROSS APPROACH-SOME RESULTS

In a set of 90 triple test cross progeny families produced by crossing 30 homozygous and genetically diverse varieties of wheat with three testers and grown in two years, Singh (1980) reported that the fixable and unfixable components of epistasis were equally sensitive to the environmental change. However, the response of dominance component to year difference was negligible as compared to that of additive genetic component, which was highly sensitive to micro- as well as to macro- environmental differences [12].

5. TRIPLE TEST CROSS APPROACH-SOME RESULTS

Phougat and Panwar [13,14] raised forty eight triple test cross families and 16 varieties of bread wheat under two environments (timely and late sown) to detect and measure the interactions between the environments and additive, dominance and epistatic effects of the genes for seven metric traits including grain yield and its component traits. In both environments, epistasis was important for grain yield and its component traits. The additive gene effects were more sensitive to environmental changes than dominance gene effect, suggesting superiority of hybrids in terms of stability. Additive × additive epistasis (i) was relatively less sensitive to environmental change than additive × dominance and dominance × dominance (j and l) components of epistasis. Testers were also found to be adequate for all the traits. Though both the additive (D) and dominance (H) components were significant for all the traits in both the environments (except dominance component for 1000-grain weight (g) under both the environments, the D component was relatively more important in all the cases. Exactly similar results were obtained regarding the sensitivity of additive, dominance and epistatic components to environmental differences in another set of 45 wheat triple test cross families raised under two environmental conditions (normal and late sowings). More sensitivity of additive component to environmental differences was also noted by Singh (1990) in 324 triple test cross families produced from three wheat crosses (HD 2009 × WH 147, NP 876 × HD 2160 and Sonalika × WL 711) [15].

In sixty Triple Test Cross families, produced by crossing 20 pure breeding varieties/strains of wheat with three testers to detect epistasis, test and estimate D and H components of genetic variation for six metric traits at two locations, it was observed that epistasis was significant for plant height, 1000-grain weight and grain yield. The component D (Additive) was more important than H (Dominance) for almost all the character studied [16]. In 1996, they used the data of these families to study interaction of additive, dominance and epistatic effects with environment. Additive gene effects were more sensitive to environmental differences than the dominance gene effects, indicating more stability of heterozygous genotypes than the homozygous varieties. However, non-fixable epistasis was more sensitive than fixable epitasis.

Similarly, the results of several other such studies carried out in wheat also indicate that the additive gene effects are sensitive to environmental change than the dominance gene effects [17,18].

6. CONCLUSIONS

Based on results discussed above regarding the sensitivity of variance components to environmental differences in wheat a few generalizations can easily be made (i) Additive genetic component and unfixable epistasis respond more to the change in environmental conditions than the dominance component and fixable epistasis, (ii) heterozygotes exhibit higher stability than the corresponding homozygotes, indicating superiority of hybrids. Since the development of hybrid wheat varieties has not so far been successful at commercial scale, the best way to increase the magnitude of dominance variation in this cereal is to increase magnitude of homozygous genomic heterosis (intergenomic heterozygosity) and (iii) though the degree of dominance may vary from character to character and from material to material for the same character, it does not vary too much between the environments.

Job of plant breeder is very difficult in choosing selection criteria under biotic and abiotic stress environments for combining high yield with resistance to adverse biotic and abiotic factors leading to poor yield. The information about the relative magnitudes of genetic parameters over a range of environments may help in making the plant breeding programme scientifically more-sound. However, while dealing with a breeding for dry areas, one must try to screen his material at the earliest segregating stage in the target environmental conditions to avoid the risk of losing highly drought resistant genotypes by selecting for one or more cycles in a favourable environment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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