Role of combining ability to develop higher yielding wheat (*Triticum aestivum* L.) genotypes: An overview

Syed Ahtisham Masood[1], Shoaib Ahmad[1], Muhammad Kashif[1] and Qurban Ali[1,2]

[1.] Department of Plant Breeding and Genetics, University of Agriculture Faisalabad,
[2.] Centre of Excellence in Molecular Biology, University of the Punjab Lahore, Pakistan
Corresponding author E-mail: s.ahtisham01@gmail.com, saim1692@gmail.com

Abstract: *Triticum aestivum* is an important cereal crop, grown through out the world as staple food for most of the people of world. It is very important to improve grain yield of wheat to nourish rapid growing population of world. Various conventional and non-conventional breeding methods and biometrical approaches have been used to achieve the goal of production. Combining ability analysis interprets the type and amount of various types of gene actions governing the expression of these metric traits. Direct selection for yield, in plant breeding program, may produce misleading results because yield is a complex polygenic trait, influenced greatly by the environmental fluctuations. Knowledge on genetic variability and relationship between various agronomic traits and yield is crucial for the success of breeding program. When improvement of the complex associated traits is desired, understanding of combining ability effects of grain yield and its component traits benefits in defining which character to choose. The present review described the use of general and specific combining ability to develop high yielding wheat varieties. The higher value of general combining ability suggested that the inbred lines may be used for the development of synthetic varieties through pure line selection, pedigree selection or recurrent back cross selection while higher specific combining ability suggested that the inbred lines may be used to develop hybrids to improve grain yield of wheat through heterosis breeding program.
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1. Introduction

Wheat is regarded as one of the most imperative crop, extensively cultivated throughout the world, with main purpose of human consumption, supporting approximately 35% of the world's population and 95% of wheat grown today is hexaploid (2n=6x), which is used in bread making and other bakery products (Debasis and Khurana, 2001). The protein found in wheat is called gluten which renders wheat a multipurpose crop, and is a primary protein source for world's inhabitants. It is also regarded as an important food and feed crop based upon its production, utilization, nutritive value, and adaptation (Hogg *et al*., 2004). Based upon, area and production wheat ranks 1st globally among the cereal crops. It accounts for more than 1/3rd of the total world's cereal crops and is main source of calories for more than 1.5 billion people in the world (Reynolds *et al*., 1999). Due to these facts wheat deserves special attention. Area under its cultivation was 8.69 Mha during 2012-13 and its production was 24.30 M tonnes, sharing about 12.5% in agri. sector and 2.6% in GDP of Pakistan (Pakistan Economic survey, 2012-13). Sustainable increase in production of wheat requires breeders to explore possible ways to achieve the objectives. So, the main objective of breeders is to develop wheat cultivars with high yielding ability (Ehdaie and Waines, 1989). The yield is considered to be a complex quantitative trait because knowledge of factors responsible for high yields has been rendered difficult (Singh *et al.* 2010). Selection based upon these estimates helps to improve complex associated traits related to yield (Sokoto *et al*., 2012; Mohammadi *et al*., 2012; Ahmad *et al*., 2010; Anwar *et al*. 2014; Ali *et al*. 2013; Khan *et al*. 2014; Tariq *et al*. 2014; Muhammad *et al*. 2013). Breeders should try development high yielding varieties by crossing good general combiners for grain yield and transgressive segregants should be selected from subsequent hybrids genotypes. Assessment of GCA effects for grain yield and its components offers an important mean in selecting parental genotypes to develop high yielding hybrids (Ali *et al*. 2014; Qamar *et al*. 2014ab; Ali *et al*. 2014abc; Azam *et al*. 2014; Jahangir *et al*. 2014).

2. Combining ability estimations for the improvement of grain yield in wheat

Sheikh and Singh (2000) stated highly significant differences for SCA and GCA in wheat genotypes for all the traits under stress and normal field conditions. Additive genetic component was of prime importance in inheritance traits studied excluding grain yield/plant and tillers/plant, in which non-additive components were superior. They stated that, desirable transgressive segregant is one having both or at least one parent with good general combining ability (GCA). Subhani and Chowdhry (2000) observed that plant height, heading days, length of spike and 1000-grain weight to be associated with narrow sense heritability. Moreover, additive genetic effects were more prevalent than non-additive genetic effects. Saeed *et al.* (2001) examined specific imperative morphological and physiological traits of six wheat varieties using three of them as testers and three as lines. The grains number/spike tillers/plant and grain yield in Chakwal-86 exhibited highest positive GCA estimates, whereas, Barani-83 shown highest positive GCA effects for flag leaf area.

Rehman *et al.* (2002) obtained significant mean squares for specific combining ability (SCA) and general combining ability (GCA) variances. Non additive gene action was reported as SCA variance had higher magnitude as compared to GCA variance for all the yield traits. Jag *et al.* (2003) studied F_1 hybrids with their parents for gaining more yield. Without days to maturity all the characters showed significant mean square in female × male interaction. Maturity days and heading days were regulator by additive genetic action. Singh *et al.* (2003) executed non-additive type of gene action was witnessed for the yield parameters. Awan *et al.* (2005) evaluated that Inqlab-91 ascertained a good general combiner for one thousand grain weight and grain yield/plant. Additionally, for cross combination, Chakwal-86 × Inqilab-91, significant results of SCA for grain yield/plant was witnessed. Saeed *et al.* (2005) found that mean squares of SCA were highly significant for 1000-grain weight, spike density, grain yield/plant and grains/spike. Whereas, mean squares for general combining ability for spikelets/spike were significant, but for 1000-grain weight, yield/plant and grains/spike were non-significant.

Sharma and Garg (2005) executed presence of additive and pre-dominant non additive genetic effects. Cross combinations, UP-2338 × Lok-1, WH-137 × Lok-1 and Job-151 × Lok-1, were found to be exceptionally good specific combiners. Farooq *et al.* (2006) stated significant results of GCA for the traits like numbers of tillers/plant, plant height, grains/spike, spikelets/spike and flag leaf area. Higher specific combining ability variances for plant height, tillers/plant, spikelets/spike, yield/plant and1000-grain weight showed the presence of non-additive genetic effects. Hasnain *et al*. (2006) evaluated that the cultivar Pasban-90 was the superior general combiner for seeds/ear and the cross-combinations 6039-1 x 6529-11 and TW-161 x 6039-1 were the good specific combiners for spikelets/ear and length of ear. Mahmood *et al.* (2006) recorded significantly positive association of grain yield with spike length, plant height and biological yield at genotypic level. Highly significant and negative association between 1000-grain weight and grain yield was stated. Mousavi *et al.* (2006) reported both additive genetic effects and non-additive genetic effects for the traits under study using ten genotypes and their 41 F_1 hybrids, which were significantly different as proved by analysis of variance. Non-additive gene action was observed for flag leaf area, 50% heading, spikelets/spike, seed yield, grains/spike and seed weight. However, for spike length and peduncle length additive genetic effects were of major importance. Nazir *et al*. (2006) analyzed that GCA mean squares were greater than those of specific CA effects for all the characters except, number of seeds per ear and 1000-seed weight. Other traits expressing high SCA effects showed non-additive gene action.

Saleem *et al*. (2006) computed positive and significant correlation was reported for yield/plant with spikelets/spike, flag leaf area, tillers/plant, spike length and thousand grain weight but, non-significant correlation was detected in case of plant height. Additionally, Positive association of 1000-grain weight with tillers count/plant, spike length, plant height and number of spikelets/spike was witnessed but was negative for plant height. Saleem and El-Sawi (2006) reported that wheat genotypes could be chose as genetic material to improve great yielding wheat cultivars in subsequent breeding schemes. Singh *et al*. (2006) found GCA was comparatively higher for plant length, days to heading, 1000-seed weight, plant length and seed production/plant. SCA was high for number of spikelets/ear, plant tillers and seeds/ear. Additive type of genetic effects was seen for plant length, days to flowering, weight of 1000-seeds and seed production/plant.

Vanpariya *et al.* (2006) suggested the superiority of additive genetic effects for plant height, heading days, spike length and spikelets/spike. Non additive genetic effects were dominant in case of tillers/plant, peduncle length, days taken to maturity, 100-grain weight, grains/per spike, grain yield/spike and grain yield/plant. Esmail (2007) evaluated high values of specific combining ability showed the presence of significant epistasis for these characters. Moreover, chiefly non-additive genetic effects for all the traits were observed. Gorjanovic and Balalic (2007) inspected good specific combining effects were interconnected with cross combination of two parents, having at least one parent as a good general combiner for many traits. Hassan *et al.* (2007) studied that additive genetic effects were of prime importance because GCA variance was predominant for traits like grain weight/spike and grain/spike. While, traits like grain yield/plant, effective tillers/plant, and 1000-grain weight presented non-additive genetic effects based upon high SCA variances.

Kamaluddin *et al*. (2007) indicated significant GCA and SCA effects for 1000- grain weight and yield were seen to be originated from parents having different types of GCA effects (low x low, medium x low, high x low and high x high). The single seed descent method can be applied to determine additive type of genetic effects while, dominant type of gene effects could be prominent in hybrid breeding programmes. Munir *et al*. (2007) revealed a significant and positive association, with number of tillers/plant, flag leaf area, length of spike, grains/spike, grain yield/spike and thousand-grain yield. The association between these traits indicated that they are controlled by certain common genes. Bikram and Ahmad (2008) found best GCA for traits like effective tillers/plant, grain weight/plant and grains/spike. Farooq *et al*. (2011b) witnessed majority of non-additive effects for tillers/plant, thousand grain weight, spikelets/spike, grains/spike and grain weight/plant. Maximum over dominance and additive variance were obtained for plant height under normal and late sowing. Khan *et al.* (2008) found that significant and positive association was exhibited by number of spikes/m^2, height of plant and 1000-grain weight with grain weight/plant. On the other hand negative correlation of grain yield/plant was witnessed with heading days and maturity days. Significant positive and direct effects on grain yield/plant by maturity days, spikes/m^2 and 1000-grain weight were observed. The indirect effect of heading days and plant height by maturity days and 1000-grain weight on grain yield was found.

Kumar and Sharma (2008) studied assistive gene action, non-additive gene action and digenetic epistatic model for various important yield traits in bread wheat. They reported additive genetic regulation for grains/spike and 1000-grain weight. Whereas, spikes/plant, biological yield and grain yield/plant were under non-additive genetic control. Moreover, duplicate epistasis and di-genic type of interactions were also witnessed for these characters. Mahpara *et al.* (2008) analyzed wheat genotypes for combining ability of many morphological characters which showed significant results for GCA effects. Inheritance of traits like plant height, tillers/plant and spikelets/spike were found to be controlled by additive genetic effects. Majumder *et al.* (2008) observed that genotypic and phenotypic variances were highly significant for all the characters but phenotypic variances were little high as usual. In most of the traits coefficients of genotypic correlation were greater than the corresponding coefficients of phenotypic correlation. Akbar *et al.* (2009) estimated higher GCA and SCA for fertile tillers/plant, plant height, days to heading, length of spike, spikelets/spike, 1000-grain weight, days to maturity and grain weight/plant. Dogan (2009) carried out an experiment with seven different durum wheat genotypes and figured out correlation between height of plant, grains/spike, grain weight/spike, yield and 1000-grain weight along with direct and indirect effects of these characters on the grain yield/plant were observed. Significant direct effect on grain yield by plant height, grains/spike, 1000-grain weight and test weight was observed.

Khokhar *et al*. (2009) reported positive and highly significant association of grain yield/plant with days to maturity but association was negative and highly significant for plant height. The highest positive direct effect of days to maturity on yield was reported.

Khan and Dar (2009) observed genotypic correlation coefficients were higher as compared to phenotypic coefficients of correlation. Grain yield showed a significantly positive association with fertile tillers/plant, spikelets/plant and thousand grain weight at phenotypic and genotypic levels. Cifci and Yagdi (2010) evaluated higher the combining ability for height of plant, spikelets/spike, length of spike, 1000-grain yield, grains/spike and grain weight/spike. Ajmal *et al.* (2011) studied that peduncle length displayed partial dominance with additive gene action based upon genetic analysis. In case of flag leaf area, plant height, tillers/plant, spike length and grain weight/plant, over-dominance type of genetic feat was observed. Farooq *et al.* (2011a) determined additive effects were significant for flag leaf area, spikelets/spike and grain yield. Kapoor *et al*. (2011) figured out higher GCA and SCA effects and variance for grain yield. Kulshreshtha and Singh (2011) estimated higher GCA in saline conditions for spikelets/spike and plant height that presented additive genetic effects. Majeed *et al*. (2011) found that predominantly, non-additive gene action was witnessed, based upon GCA and SCA variances, for yield/plant. Punia *et al.* (2011) reported higher GCA for better production, high temperature tolerance and chlorophyll content. Shabbir *et al.* (2011) found that GCA estimate for grains per spike showing additive type of gene action. Ankita *et al.* (2012) reported additive genetic effects as well as non-additive genetic effects for the studied traits based upon the estimate of variance due to GCA, SCA and their ratio. Ashadusjaman *et al.* (2012) reported significantly positive specific combining ability effects were detected for crosses SA-92 × Kherishowed, Sebia × HT-7 and Sebia × SA-92 for root length.

El-Mohsen *et al*. (2012) revealed higher values for genotypic correlation coefficients than the phenotypic correlation coefficients for many studied traits. The traits like tillers/plant, spike length, 1000-grain weight, spikelets/spike and grains number/spike had positive association to grain yield/plant at both levels of genotype and phenotype. Jain and Sastry (2012) found that highest magnitude of significantly positive SCA effects were exhibited by the hybrid crosses, WH-542 × K-65 and WH-542 × Raj-3077. Kalimullah *et al.* (2012) evaluated that phenotypic and genotypic coefficients of variation were greater for flag leaf area, grain yield/plant and tillers/plant. Srivastava et al. (2012) found that GCA effects were considerably lower than that of SCA effects for every trait studied showing non-additive gene action, highlighting the future success of heterosis breeding. Fellahi *et al.* (2013) worked on 24 wheat genotypes, whose results indicated positive association of grain yield to biological yield, number of spike/plant and straw yield/plant based upon their correlation coefficient values. Gelalchal and Hanchinal (2013) found genotypic and phenotypic association between grain yield and other components like tillers/plant, grains/spike, total biomass/plant, spikes/m^2, 1000-grain weight and harvest index were extremely significant. Total biomass, harvest index, plant height and days to flowering contributed significant direct impact on grain yield based upon path coefficient analysis.

Lohithaswa *et al*. (2013) observed additive gene action for each important yield trait excluding grains/spike. The lines DK-1001 and Vijay and testers Raj-1555 and DWR-1006 had highly significant value of GCA effects for yield and related attributes. Raj and Kandalkar (2013) observed as GCA variances for yield/spike, number of tillers/plant, first inter nodal length and grain weight/spike and SCA variances for stem girth was non-significant. Tahmasebi *et al.* (2013) assessed higher genetic and phenotypic coefficients of variability (GCA and SCA) were detected for number of spike/plant, 1000-grain weight and grain yield/plant. Grain yield presented significantly positive association with 1000-grain weight, plant height and number of spike/plant based upon correlation analysis.

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