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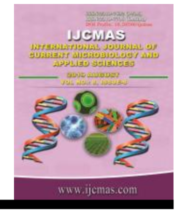

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Combining Ability Studies for Morpho-Physiological, Yield, Yield Attributes Nitrogen Use Efficiency and Its Related Traits in Bread Wheat (*Triticum aestivum* L.)

Mahalaxmi K. Patil and S.A. Desai*

Department of Genetics and Plant Breeding, College of Agriculture, University of Agricultural Sciences, Dharwad 580 005, India

**Corresponding author*

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A B S T R A C T

In India, wheat is the most important cereal crop and plays a major role in food and nutritional safety. Worldwide, there is a growing interest in the development of wheat cultivars that are more effective in utilizing nitrogen (N) and better suited to N constraints. he objective of this research was to investigate the comparative significance of general (GCA) and specific (SCA) combining ability in a set of wheat genotypes with promising lines and their corresponding half-diallel crosses. Combining yield ability for yield attributes, nitrogen use efficiency (NUE) and its associated characters were studied in twelve bread wheat genotypes and their sixty six F_1s derived from half-diallel crosses and assessed under 50 per cent of recommended dose of nitrogen condition using three replicated alpha lattice design. Variance due to GCA has been found to be important for all traits. This indicates the significance of additive genetic variance in regulating the expression of these characters. Significance of variance due to SCA was noted for all traits except for grain protein content and nitrogen harvest index, showing the significance of non-additive genetic variance in regulating the expression of these characters. In most of the traits, the variance ratios were less than unity except for the grain protein content and nitrogen harvest index, thus representing the preponderance of non-additive gene action for most characteristics. Parents namely, 3 SATYN 9402, K9107, HD 2967 and 46 IBWSN 1005 were the best general combiners and crosses namely, 3 SATYN 9402 x K9107, 3 SATYN 9402x HD 2967, 3 SATYN 9402x 46 IBWSN 1005, 3 SATYN 9402 x DBW 14, HD 2967x 46 IBWSN 1005 and WH 1022x K9107 found to be the best specific combiners for yield and NUE associated traits.

Introduction

Wheat (*Triticum* spp.) is the major cereal grain in the world and belongs to the Graminae family. Due to the acreage it occupies, high productivity and the prominent position it maintains in global food grain trade, it has been defined as the' King of cereals.' India is the world's second-largest wheat producer after China and the country's second-largest food crop. Wheat played a crucial role in stabilizing the country's food grain production. As land and water resources are limited, the rise in wheat production can only be accomplished by raising the average yield. Moreover, enhanced agricultural production around the globe as a result of the green revolution was primarily based on the use of mineral fertilizers, which resulted in an rise in worldwide N fertilizer consumption from 10.8

million tonnes in the year 1960 to 85.6 million tonnes in the year 2000, and is expected to raise to 240 million tonnes by 2050 (Crews and Peoples, 2004).

The efficiency with which plant uses N, a lot of attention has been paid to the nitrogen use efficiency (NUE). NUE may be described as the proportion of grain yield or biomass by the nitrogen supply available in the soil (Moll *et al.,* 1982). According to Moll *et al.,* (1982), N use efficiency (NUE) in cultivar growth can be split into two components: (i) uptake efficiency (UPE) (complete plant N / N supplied), which is the ability of the crop to extract N from the soil; and (ii) use effectiveness (UTE) (grain yield / total plant N), which measures the plant's ability to transform the already absorbed N into grain yield in the plant. Plants ability to capture N from the soil relies on factors including type of soil, climate, and species. Genetic variability for both N uptake efficiency and N utilization efficiency exists for a large amount of crop plants (Hirel *et al.,* 2007). In addition, the occurrence of interactions between the genotype and N level resulted to the conclusion that the best performing crop varieties at high N fertilization input are not necessarily the best varieties at reduced N supply (Gallais and Coque, 2005).

Agricultural crops are inefficient in the uptake and utilization of fertilizer nitrogen, including wheat. Reports have shown that the nitrogen use efficiency NUE) in wheat is around 40-50 percent, resulting in the loss of more than 50 per cent of the applied fertilizer nitrogen to the environment and a potential source of pollution and extra costs for farmers (Barraclough *et al.,* 2010, Gorny *et al.,* 2011 and Hawkesford, 2012). Increasing emphasis on breeding wheat cultivars with enhanced NUE to reduce excessive nitrogen fertilizer input and maintain an acceptable yield is therefore a worldwide issue (Hirel *et al.,* 2007 and Foulkes *et al.,* 2009). As a result, NUE enhancement will simultaneously boost farmers ' earnings and decrease the adverse environmental impact of N loss on the environment and its food production impact. Nitrogen-use efficient crop varieties may be a great choice for ensuring sustainability in agricultural systems and meeting future customer requirements, particularly in the face of changing climate change environments.

It is of great importance to improve the nitrogen use efficiency and yield potential of the wheat varieties information on the genetic mechanisms of the wheat varieties, such combining ability. Often breeders face issues in selecting those parental lines, which can provide greater frequency of most desirable segregants in different cross combinations. To achieve this goal, knowledge of prepotency of parental lines for combining ability is very useful in selecting desirable lines (Ashadusjam *et al.,* 2012). In view of the above facts, the current experiment has been undertaken to estimate the combining ability effects of different parents and crosses in F1 population and to determine the additive and non-additive genetic effects of yield and NUE related traits.

Materials and methods

Twelve diverse parents, 2 WYCYT 34, WH 1022, 5 CISA HTEM 10212, GW 322, 3 SATYN 9402, K9107, HD 2967, RAJ 1972, PBW 343, 5 CISA HTEM 10211, 46 IBWSN 100, DBW 14 were chosen as parents on the grounds of their yield potential and NUE component traits such as harvest index, nitrogen uptake efficiency, nitrogen utilization efficiency and NUE etc. These parents were crossed in all possible combinations excluding reciprocals to generate sixty-six F_1 hybrids consisting of experimental components for this experiment and the experiment was carried out with three replications in alpha lattice design. At All India Coordinated Wheat Improvement Project, University of Agricultural Sciences, Dharwad, all the F_1 hybrids along with their parents were grown in 6 rows of 3 meter long bed with a spacing of 20 cm between rows and plant to plant distance within row was 10 cm under 50 per cent of the recommended dose of nitrogen (N) during *rabi* 2017-18.

Twenty one traits namely, chlorophyll content at booting stage, anthesis stage and grain filling stage, days 50 per cent heading, days to maturity, plant height, number of productive tillers per plant, spike length, awn length, number of spikelets per spike, number of grains per spike, thousand grain weight, grain yield, biomass, harvest index, grain protein content (%), nitrogen harvest index, total nitrogen uptake, nitrogen uptake efficiency, nitrogen utilization efficiency and nitrogen use efficiency were recorded on randomly chosen competitive parent plants and from each replication in parents and F1s. The data was analyzed for combining capacity according to Griffing's Method 2, Model I (1956).

Results and Discussion

Analysis of variance for combining ability

The analysis of variance for combining ability for morpho-physiological, yields, yield attributes, NUE and its associated traits is presented in (Table 1). ANOVA for combining ability revealed that variance due to general combining ability (GCA) was found to be significant for all the attributes. This indicated the importance of genetic additive variance in regulating the expression of these characters. Significance of variance owing to specific combination ability (SCA) was noted for all characters except protein and nitrogen harvest index, showing the significance of non-additive genetic variance in regulating the expression of these characters. With the exception of protein and nitrogen harvest index, the variance proportions were less than unity in most of the attributes, thus representing the preponderance of dominant gene action (presence of more non-additive gene action) for most characters.

Likewise, Singh *et al.,* (2012) and Ranjitha *et al.,* (2018) also recorded non-additive variance in expression of quantitative characters. In this research, the preponderance of dominance (non-additive) effects indicated that selection techniques that eliminate non-additive masking effects and take benefit of the additive variance should be used to enhance nitrogen efficiency characteristics in the low-N environment.

General combining ability effects of the parents

Estimate of *gca* effects of the parents for different yield, yield attributes, NUE and related traits are presented in Table 2.

General Combining Ability (GCA) was defined by Sprague and Tatum (1942) as the average performance of line or tester in series of hybrid combinations. Among twelve parents The NUE parents namely, 3 SATYN 9402, K9107, HD 2967 and 46 IBWSN 1005 manifested significant and positive gca effects for most of the attributes (mainly yield, Harvest index, NUtE, NUE) studied.

These parents were not only good general combiners but their per se performance was also superior for most of the characters studied. For future breeding programmes, genotypes with high GCA values for economically valuable characteristics such as grain yield, NUE and its related components should be used to boost the wheat yield. Mahantashivayogayya *et al.,* (2004), Joshi *et al.,* (2004), Khan *et al.,* (2007), Ranjitha *et al.,* (2018) revealed similar outcomes.

Table.1 ANOVA for combining ability for morpho-physiological, yield, yield attributes, NUE and related traits in 12 × 12 half diallel crosses

Character	df	Chlorophyll content at booting stage	Chlorophyll content at anthesis stage	Chlorophyll content at grain filling stage	Days to heading	Days to maturity	Plant height	Number of productive tiller per meter	Spike length	Awn length	Number of spikelet's per spike	Number of grains per spike
GCA	11	13.04 **	10.38**	8.19 **	11.38**	75.52 **	84.99**	10.63**	2.02 **	0.99 **	2.30 **	20.59 **
SCA	66	7.11 **	8.21 **	6.63 **	8.20 **	22.76 **	38.63 **	3.20**	1.98 **	0.81 **	2.31 **	20.41 **
Error	151	0.62	0.57	0.55	0.25	0.36	0.67	0.73	0.10	0.05	0.32	2.80

Character	df	Thousand grain weight	Grain yield	Biomass	Harvest index	Grain protein content	Nitrogen harvest index	Total nitrogen uptake	Nitrogen uptake efficiency	Nitrogen utilization efficiency	Nitrogen use efficiency
GCA	11	43.44 **	12.38 **	22.67**	94.68**	1.12**	11.53**	0.01**	0.008**	18.27 **	20.35 **
SCA	66	7.52**	1.81**	8.53 **	10.85**	0.16	1.50	0.001**	0.002**	3.75*	2.97 **
Error	151	2.73	0.35	2.26	1.53	0.20	1.11	0.0004	0.001	1.32	0.58

Table.2 Estimates of general combining ability effects of 12 parents used in 12 × 12 half diallel crosses study

Parents	Chlorophyll content at booting stage	Chlorophyll content at anthesis stage	Chlorophyll content at grain filling stage	Days to heading	Days to maturity	Plant height	Number of productive tiller per meter	Spike length	Awn length	Number of spikelet's per spike	Number of grains per spike
2 WYCYT 34	-0.79 **	-0.87 **	-1.10 **	-1.54 **	-4.11 **	-0.50 *	2.02 **	-0.29	-0.33 **	-0.03	-0.17
WH 1022	-0.09	-0.56 **	-0.44 *	1.03 **	1.79 **	1.96 **	0.14	0.44	-0.44 **	0.37 *	1.14 **
5 CISA HTEM 10212	1.39 **	0.84 **	0.96 **	0.44 **	0.96 **	1.10 **	0.33	-0.30	0.02	0.16	0.40
GW 322	-1.27 **	-0.77 **	-0.85 **	-0.14	2.46 **	-0.38	-1.05 **	-0.60	-0.14 *	0.10	0.31
3 SATYN 9402	2.16 **	2.16 **	1.55 **	0.65 **	-0.68 **	2.43 **	0.69 **	0.37	0.05	0.31 *	0.93 *
K9107	0.23	-0.25	-0.18	0.84 **	-0.28	3.02 **	-0.52 *	0.44	0.11	-0.54 **	-1.59 **
HD 2967	-0.24	-0.20	-0.27	-0.71 **	-2.94 **	3.94 **	0.45 *	0.39	0.34 **	0.60 **	1.82 **
RAJ 1972	-0.45 **	0.07	0.09	-0.54 **	1.01 **	-3.04 **	-0.83 **	-0.37	-0.14 *	-0.41 **	-1.22 **
PBW 343	-0.52 **	-0.64 **	-0.34	0.53 **	1.34 **	-3.54 **	-0.60 **	-0.15	0.11	-0.77 **	-2.29 **
5 CISA HTEM 10211	-0.56 **	-0.40 *	-0.24	0.06 **	1.63 **	-1.53 **	-0.98 **	-0.37	-0.25 **	-0.20	-0.58
46 IBWSN 1005	0.59 **	0.66 **	0.84 **	0.89 **	2.32 **	-1.14 **	0.10	0.24	0.43 **	0.16	0.49
DBW 14	-0.44 **	-0.04	-0.01	-1.52 **	-3.49 **	-2.32 **	0.24	0.20	0.23 **	0.25	0.77
Gi-Gj 95%	0.59	0.57	0.55	0.38	0.46	0.62	0.64	0.24	0.17	0.42	1.26
Gi-Gj 99%	0.78 **	0.75 **	0.73 **	0.50 **	0.60 **	0.81 **	0.85 **	0.31	0.23 **	0.56 **	1.66 **

Contd….

Parents	Thousand grain weight	Grain yield	Biomass	Harvest index	Grain protein content	Nitrogen harvest index	Total nitrogen uptake	Nitrogen uptake efficiency	Nitrogen utilization efficiency	Nitrogen use efficiency
2 WYCYT 34	-0.93 *	-0.40 **	3.15 **	-3.57 **	-0.37 **	-1.01 **	0.01 *	0.02 *	-1.76 **	0.52 **
WH 1022	-1.84 **	-0.16	0.54	-0.97 **	-0.18	1.02 **	-0.01 *	-0.02 *	0.62 *	-0.21
5 CISA HTEM 10212	-1.63 **	-0.43 **	-0.82 *	-0.41	-0.22	-0.60 *	-0.01 *	-0.02 *	0.07	-0.55 **
GW 322	-0.99 *	-1.00 **	-0.74	-2.06 **	-0.13	0.12	-0.02 **	-0.03 **	-0.66 **	-1.28 **
3 SATYN 9402	3.94 **	2.26 **	0.91 *	4.93 **	0.58 **	1.72 **	0.04 **	0.06 **	1.96 **	2.90 **
K9107	2.18 **	1.20 **	0.09	2.90 **	0.35 **	1.00 **	0.02 **	0.03 **	1.28 **	1.54 **
HD 2967	1.89 **	0.46 **	-1.53 **	2.81 **	0.24 *	0.23	0.002	0.003	0.95 **	0.59 **
RAJ 1972	-1.26 **	-0.56 **	0.92 *	-2.24 **	-0.02	-0.32	0.001	0.002	-1.36 **	-0.72 **
PBW 343	0.05	-0.52 **	-0.97 *	-0.61	0.02	-0.25	-0.01 *	-0.01 *	-0.41	-0.67 **
5 CISA HTEM 10211	-0.46	-0.60 **	0.06	-1.52 **	-0.03	-0.23	-0.01 *	-0.01 *	-0.94 **	-0.77 **
46 IBWSN 1005	-0.76	0.43 **	-1.05 **	2.33 **	0.09	-0.14	0.004	0.00	0.88 **	0.55 **
DBW 14	-0.19	-0.68 **	-0.57	-1.60 **	-0.35 **	-1.54 **	-0.02 **	-0.02 **	-0.62 *	-0.87 **
Gi-Gj 95%	1.24	0.44	1.12	0.93	0.34	0.79	0.02	0.02	0.86	0.57
Gi-Gj 99%	1.63 **	0.59 **	1.48 **	1.23 **	0.45 **	1.04 **	0.02 **	0.03 **	1.14 **	0.75 **

Table.3 Estimates of specific combining ability effects for sixty-six single cross hybrids used in the 12 x 12 half diallel study

Cross	Chlorophyll content at booting stage	Chlorophyll content at anthesis stage	Chlorophyll content at grain filling stage	Days to heading	Days to maturity	Plant height	Number of productive tiller per meter	Spike length	Awn length	Number of spikelet's per spike	Number of grains per spike
2 WYCYT 34 x WH 1022	-0.346	0.48	1.32	-1.64 **	-2.78**	0.19	-2.04 *	-2.12 **	-1.64 **	0.78	2.41
2 WYCYT 34 x 5 CISA HTEM 10212	1.88 *	1.95 **	-0.11	-0.38	-2.28 **	4.76 **	0.77	1.48 **	0.84 **	3.33 **	8.82 **
2 WYCYT 34 x GW 322	-1.23	-1.48 *	-0.44	1.20 *	2.56 **	7.54 **	0.49	-1.65 **	0.02	-0.61	-1.76
2 WYCYT 34 x 3 SATYN 9402	-0.66	-0.86	-0.16	-0.59	5.70 **	-5.83 **	-0.59	0.15	-0.93 **	-0.15	-0.38
2 WYCYT 34 x K9107	1.50 *	0.06	0.53	2.89 **	0.628	-6.07 **	-0.37	0.31	-0.26	-1.31 *	-3.86 *
2 WYCYT 34 x HD 2967	-1.40	-0.56	-0.78	4.77**	1.63 **	-7.52 **	0.65	0.70 *	-0.32	-1.78 ***	-5.27 **
2 WYCYT 34 x RAJ 1972	1.58 *	0.42	0.79	0.60	1.34 *	-1.78 *	1.60 *	-1.55 **	-0.84 **	-0.10	-0.23
2 WYCYT 34 x PBW 343	-1.79 *	-2.11 **	-3.04 **	-2.14 **	-3.32 **	-2.31 **	2.03 *	-0.34	-0.46 *	-0.41	-1.16
2 WYCYT 34 x 5 CISA HTEM 10211	2.46 **	2.14 **	1.92 **	-2.66**	-5.27 **	-2.85 **	2.41 **	0.48	-1.37 **	-0.98	-2.87
2 WYCYT 34 x 46 IBWSN 1005	-0.82	-0.85	-0.99	2.17**	2.37 **	4.30 **	0.34	-0.42	-0.78 **	-0.68	-1.94
2 WYCYT 34 x DBW 14	-2.40 **	-2.25 **	-2.77 **	2.58**	1.84 **	6.40 **	-0.13	2.01 **	0.12	0.90	2.79
WH 1022 x 5 CISA HTEM 10212	-1.43	-2.45 **	-3.54 **	-2.95 **	1.49 **	-0.27	-0.02	-0.21	-0.50 *	1.25 *	3.84 *
WH 1022 x GW 322	-1.80 *	-0.50	-1.84 **	-1.71**	-1.68 **	2.37 **	1.03	-0.38	-0.84 **	-0.68	-2.07
WH 1022 x 3 SATYN 9402	1.44	0.05	1.23	-1.50 **	-3.54 **	0.66	-0.71	-2.08 **	-0.03	-2.23 **	-6.69 **
WH 1022 x K9107	2.67 **	3.40 **	0.70	-1.02 *	0.39	-1.66 *	3.44 **	6.14**	-0.02	-2.05 **	-6.17 **
WH 1022 x HD 2967	-1.00	-1.45 *	0.32	-0.14	-0.94	4.52 **	-0.13	1.30 **	1.18 **	1.48 **	4.43 **
WH 1022 x RAJ 1972	-1.99 **	-3.63 **	-1.88 **	5.03 **	3.44 **	-0.77	0.15	-0.28	-0.87 **	0.49	1.46
WH 1022 x PBW 343 x	1.21	1.21	0.92	2.96 **	5.77 **	5.47 **	0.58	-0.06	0.45 *	2.18 **	6.53 **
WH 1022 x 5 CISA HTEM 10211	-1.68 *	-1.59 *	-2.95 **	5.77 **	6.82 **	-9.17 **	0.30	-1.35 **	0.68 **	-0.39	-1.18
WH 1022 x 46 IBWSN 1005	-3.81 **	-4.29 **	-2.46 **	-0.73	-3.54 **	-3.17 **	-3.11 **	0.99 **	0.89 **	0.59	1.75
WH 1022 x DBW 14	2.39 **	0.87	1.46 *	3.01 **	3.94 **	-3.29 **	-0.25	0.35	0.92 **	-0.84	-2.53
5 CISA HTEM 10212 x GW 322	1.95 **	0.63	0.57	0.55	1.49 **	-16.43 **	-1.16	0.90 **	0.70 **	-1.8 **	-5.33 **
5 CISA HTEM 10212 x 3 SATYN 9402	1.73 *	2.15 **	2.64 **	3.43 **	6.63 **	-11.67 **	1.44	-2.98 **	-1.91 **	-3.34 **	-9.95 **
5 CISA HTEM 10212 x K9107	0.03	-0.05	-0.53	4.58 **	3.56 **	-8.43 **	-0.02	-0.14	0.56 *	0.16	0.57
5 CISA HTEM 10212 x HD 2967	0.15	0.71	-0.97	-0.88	1.557 **	-8.11 **	-2.32 **	0.08	-0.18	-0.97	-2.84
WH 1022 x RAJ 1972	-1.99 **	-3.63 **	-1.88 **	5.03 **	3.44 **	-0.77	0.15	-0.28	-0.87 **	0.49	1.46
WH 1022 x PBW 343	1.21	1.21	0.92	2.96 **	5.77 **	5.47 **	0.58	-0.06	0.45 *	2.18 **	6.53 **
WH 1022 x 5 CISA HTEM 10211	-1.68 *	-1.59 *	-2.95 **	5.77 **	6.82 **	-9.17 **	0.30	-1.35 **	0.68 **	-0.39	-1.18
WH 1022 x 46 IBWSN 1005	-3.81 **	-4.29 **	-2.46 **	-0.73	-3.54 **	-3.17 **	-3.11 **	0.99 **	0.89 **	0.59	1.75
WH 1022 x DBW 14	2.39 **	0.87	1.46 *	3.01 **	3.94 **	-3.29 **	-0.25	0.35	0.92 **	-0.84	-2.53
5 CISA HTEM 10212 x GW 322	1.95 **	0.63	0.57	0.55	1.49 **	-16.43 **	-1.16	0.90 **	0.70 **	-1.8 **	-5.33 **
5 CISA HTEM 10212 x 3 SATYN 9402	1.73 *	2.15 **	2.64 **	3.43 **	6.63 **	-11.67 **	1.44	-2.98 **	-1.91 **	-3.34 **	-9.95 **
5 CISA HTEM 10212 x K9107	0.03	-0.05	-0.53	4.58 **	3.56 **	-8.43 **	-0.02	-0.14	0.56 *	0.16	0.57
5 CISA HTEM 10212 x HD 2967	0.15	0.71	-0.97	-0.88	1.557 **	-8.11 **	-2.32 **	0.08	-0.18	-0.97	-2.84
5 CISA HTEM 10212 x RAJ 1972	-3.87 **	-2.91 **	-2.27 **	0.63	-2.40 **	2.20 **	1.96 *	2.10 **	-0.39	2.04 **	6.20 **
5 CISA HTEM 10212 x PBW 343	0.63	0.13	1.57 *	-2.45 **	-3.40 **	0.40	-1.94 *	-1.19 **	-1.34 **	-0.94	-2.73
5 CISA HTEM 10212 x 5 CISA HTEM 10211	1.34	0.45	0.43	2.36 **	-0.68	12.96 **	-0.56	0.43	1.15 **	-2.18 **	-6.44 **

Cross	Chlorophyll content at booting stage	Chlorophyll content at anthesis stage	Chlorophyll content at grain filling stage	Days to heading	Days to maturity	Plant height	Number of productive tiller per meter	Spike length	Awn length	Number of spikelet's per spike	Number of grains per spike
5 CISA HTEM 10212 x 46 IBWSN 1005	1.07	0.40	1.32	-0.80	-2.71 **	6.64 **	0.70	-0.17	0.20	1.47 **	4.48**
5 CISA HTEM 10212 x DBW 14	-0.62	-0.47	1.47 *	1.27 **	1.44 *	6.97 **	1.56	-1.01 **	-0.76 **	0.71	2.21
GW 322 x 3 SATYN 9402	-3.05 **	-3.54 **	-2.69 **	-2.00 **	6.80 **	2.28 **	-1.85 *	-0.78 **	-0.39	-1.95 **	-5.86**
GW 322 x 2K9107	2.51 **	1.90 **	2.74 **	-2.52 **	-1.94 **	3.38 **	-1.30	-1.28 **	-0.29	-0.44	-1.34
GW 322 x HD 2967	-7.19 **	-9.01**	-7.30 **	0.03	-2.94 **	-6.43 **	-0.94	0.04	-0.66 **	-3.58 **	-10.75 **
GW 322 x RAJ 1972	1.75 *	1.46 *	1.40 *	1.20 *	9.77 **	-0.59	0.68	-0.27	-0.44 *	1.44 **	4.29 **
GW 322 x PBW 343	-1.18	-1.14	-1.16	3.79 **	10.77 **	0.68	-0.23	1.24 **	0.55 *	2.46 **	7.36 **
GW 322 x 5 CISA HTEM 10211	3.83 **	3.95 **	3.57 **	3.60 **	0.49	-4.20 **	0.15	-0.07	-0.17	0.55	1.65
GW 322 x 46 IBWSN 1005	2.19 **	1.82 *	1.72 *	2.43 **	-0.21	-0.89	0.41	-0.21	0.42 *	0.20	0.58
GW 322 x DBW 14	0.87	1.20	2.07 **	1.17 *	-3.73 **	-0.35	0.27	0.83 **	0.12	3.11 **	9.30 **
3 SATYN 9402 x K9107	1.39	1.63 *	0.95	-4.64 **	-2.80 **	1.47	2.63 **	2.65 **	2.06 **	1.62 **	4.84 **
3 SATYN 9402 x HD 2967	3.41 **	3.03 **	2.91 **	2.24 **	0.53	3.62 **	2.65 **	1.27 **	1.23 **	1.05 *	3.13 *
3 SATYN 9402 x RAJ 1972	1.69 *	1.91 **	1.11	1.41 **	-10.75 **	8.43 **	2.27 **	0.56	0.71 **	-0.77	-2.33
3 SATYN 9402 x PBW 343	-0.34	0.26	0.24	2.01 **	0.247	-2.00 *	-0.97	0.34	-0.54 *	-0.42	-1.26
3 SATYN 9402 x 5 CISA HTEM 10211	-4.30 **	-3.77 **	-2.56 **	1.82 **	3.30 **	-1.94 *	0.75	0.52	0.12	1.01	3.03
3 SATYN 9402 x 46 IBWSN 1005	-1.74 *	-2.15 **	-3.57 **	1.65 ***	4.94 **	-4.81 **	-3.66 **	1.79 **	0.28	0.99	2.95
3 SATYN 9402 x DBW 14	1.08	0.94	-0.45	0.39	-0.92	2.64 **	0.53	-1.31**	-0.83 **	1.17 *	3.48 *
K9107 x HD 2967	2.51 **	2.36*	2.70 **	1.39 **	2.46 **	-3.54 **	-1.13	-1.26 **	-0.07	-1.61 **	-4.85 **
K9107 x RAJ 1972	-2.11**	-3.33 **	-2.03 **	0.89	-0.16	10.04 **	0.82	0.99 **	0.48 *	2.07 **	6.19 **
K9107 x PBW 343	-2.78 **	-5.79 **	-4.40 **	4.15 **	4.84 **	-10.19 **	1.91 *	-2.06 **	-1.43 **	0.43	1.26
K9107 x 5 CISA HTEM 10211	-1.70 *	0.23	0.36	0.96 *	0.89	5.67 **	-1.71 *	0.256	0.12	0.52	1.55
K910746 x IBWSN 1005	-8.11 **	-8.11 **	-6.98 **	1.79 **	-2.13 **	4.67 **	-2.78 **	-1.944 **	-0.82 **	-0.50	-1.53
K9107 x DBW 14	-3.16 **	-2.71 **	-3.69 **	-0.14	2.68 **	-3.22 **	-2.25 **	-0.08	0.41	-0.26	-0.80
HD 2967 x RAJ 1972	3.52 **	3.54 **	2.86 **	1.77 **	-0.82	-3.54 **	-2.49 **	-0.89 **	-1.19 **	-1.07 *	-3.22 *
HD 2967 x PBW 343	-2.52 **	-2.19 **	-2.90 **	-2.64 **	-2.16 **	4.95 **	-0.40	0.49	0.07	-0.71	-2.15
HD 2967 x 5 CISA HTEM 10211	-3.53 **	-3.48 **	-3.01 **	-2.50 **	0.56	3.22 **	-1.35	0.21	0.39	1.39 **	4.14 **
HD 2967 x 46 IBWSN 1005	2.62 **	2.05 **	1.18	-1.66 **	-0.80	7.66 **	3.25 **	0.81 **	0.58 **	1.69 **	5.07 **
HD 2967 x DBW 14	-4.13 **	-4.07 **	-2.73 **	-4.26 **	1.34 *	4.13 **	4.44 **	0.97 **	-0.69 **	1.60 **	4.80 **
RAJ 1972 x PBW 343	1.43	1.82 *	1.33	2.86 **	4.22 **	0.60	-1.11	0.41	0.45 *	0.97	2.89
RAJ 1972 x 5 CISA HTEM 10211	-4.02 **	-3.02 **	-3.87 **	-0.33	5.94 **	-9.01 **	-2.06 *	-0.07	0.20	-0.94	-2.83
PBW 343 x 46 IBWSN 1005	0.03	1.26	0.82	-2.57 **	-4.09**	-0.46	-1.37	1.64 **	1.21**	-1.27 *	-3.83 *
PBW 343 x DBW 14	2.92 **	3.54 **	3.10 **	-2.16 **	5.72 **	2.91 **	-1.52	-0.29	-0.45 *	-1.36 *	-4.10 **
5 CISA HTEM 10211 x 46 IBWSN 1005	2.94 **	1.98 **	1.58 *	-0.42	1.96 **	-5.80 **	1.01	-1.64 **	-1.40 **	-0.84	-2.54
5 CISA HTEM 10211 x DBW 14	0.90	-0.08	-0.40	3.32 **	3.77 **	10.27 **	-0.13	-0.64 *	-0.13	0.40	1.19
46 IBWSN 1005 x DBW 14	-0.65	0.56	0.19	-0.85	4.75 **	-1.69 *	1.80 *	-0.01	0.33	-0.62	-1.88
Sij-Sik 95%	2.14	2.04	1.20	1.35	1.64	2.22	2.31	0.85	0.62	1.52	4.53
Sij-Sik 99%	2.82	2.70	2.64	1.79	2.17	2.93	3.05	1.12	0.82	2.01	5.98
Sij-Skm 95%	2.05	1.96	1.92	1.30	1.58	2.14	2.22	0.82	0.60	1.46	4.35
Sij-Skm 99%	2.71	2.59	2.53	1.72	2.08	2.82	2.93	1.08	0.79	1.93	5.74

Contd...

Cross	Thousand grain weight	Grain yield	Biomass	Harvest index	Grain protein content	Nitrogen harvest index	Total nitrogen uptake	Nitrogen uptake efficiency	Nitrogen utilization efficiency	Nitrogen use efficiency
2 WYCYT 34 x WH 1022	2.21	0.55	-1.42	2.45 *	0.22	-1.45	0.02	0.02	-0.09	0.70
2 WYCYT 34 x 5 CISA HTEM 10212	3.26 *	0.99	1.32	1.30	-0.03	0.51	0.02	0.02	1.03	1.27
2 WYCYT 34 x GW 322	-0.93	0.80	-0.63	2.55 *	0.32	1.08	0.01	0.01	1.36	1.02
2 WYCYT 34 x 3 SATYN 9402	-6.24 **	-1.38 *	3.22 *	-5.75 **	-0.52	-2.48 *	0.01	0.01	-3.07 **	-1.77 *
2 WYCYT 34 x K9107	-0.24	-1.88 **	-0.82	-4.11 **	-0.23	-0.47	-0.03	-0.04	-1.94	-2.40 **
2 WYCYT 34 x HD 2967	-1.67	-0.22	2.16	-2.78 *	0.05	-0.72	0.02	0.03	-1.87	-0.28
2 WYCYT 34 x RAJ 1972	-2.68	0.51	-2.10	2.95 *	-0.42	-0.63	-0.02	-0.02	2.19 *	0.65
2 WYCYT 34 x PBW 343	-3.83 *	0.19	0.33	0.22	-0.14	0.22	-0.01	-0.001	0.55	0.25
2 WYCYT 34 x 5 CISA HTEM 10211	0.48	0.41	-3.09 *	3.28 **	-0.22	0.09	-0.03	-0.04	2.60 *	0.52
2 WYCYT 34 x 46 IBWSN 1005	3.42 *	-0.39	5.18 **	-5.08 **	0.26	0.24	0.04 *	0.05 *	-3.35 **	-0.51
2 WYCYT 34 x DBW 14	1.29	0.54	4.58 **	-1.43	-0.47	0.55	0.02	0.03	-0.09	0.70
WH 1022 x 5 CISA HTEM 10212	-3.01	1.20 *	2.76	0.80	0.38	1.43	0.03	0.05	0.50	1.53 *
WH 1022 x GW 322	0.77	1.17 *	2.04	1.37	0.41	0.12	0.04 *	0.05 *	-0.21	1.50 *
WH 1022 x 3 SATYN 9402	-1.86	-0.62	-0.45	-1.10	-0.24	-2.67 **	0.00	0.003	-1.38	-0.80
WH 1022 x K9107	0.87	1.97 **	0.93	4.18 **	-0.52	-0.25	0.02	0.02	3.47 **	2.52 **
WH 1022 x HD 2967	-1.29	-1.31 *	4.82 **	-7.32 **	-0.10	-1.14	0.02	0.03	-4.60 **	-1.67 *
WH 1022 x RAJ 1972	-1.16	-0.45	-1.50	0.06	-0.20	0.54	-0.03	-0.04	0.93	-0.58
WH 1022 x PBW 343	-1.18	-1.11 *	-0.24	-2.62 *	-0.21	1.54	-0.04	-0.04	-0.16	-1.42 *
WH 1022 x 5 CISA HTEM 10211	-0.02	0.63	-4.93 **	6.19 **	0.23	2.06 *	-0.04	-0.04	4.13 **	0.80
WH 1022 x 46 IBWSN 1005	-3.77 *	-0.98	-0.40	-2.68 *	0.34	1.89	-0.02	-0.03	-0.98	-1.26
WH 1022 x DBW 14	1.48	-1.88 **	-2.78 *	-2.62 *	-0.62	-0.33	-0.05 *	-0.07 *	-0.80	-2.41 **
5 CISA HTEM 10212 x GW 322	0.003	0.40	2.46	-1.02	0.08	-0.69	0.03	0.04	-1.47	0.51
5 CISA HTEM 10212 x 3 SATYN 9402	-2.82	-2.46 **	-4.26 **	-2.45 *	-0.28	0.29	-0.08 **	-0.1 **	-0.04	-3.16 **
5 CISA HTEM 10212 x K9107	0.56	-0.71	-0.03	-1.80	-0.07	-1.25	0.0001	0.001	-1.60	-0.91
5 CISA HTEM 10212 x HD 2967	-1.56	-0.63	-0.56	-1.53	-0.56	-0.94	-0.02	-0.03	0.13	-0.80
5 CISA HTEM 10212 x RAJ 1972	3.97 *	0.36	-3.61 *	3.99 **	-0.20	-0.65	-0.02	-0.03	2.23 *	0.47
5 CISA HTEM 10212 x PBW 343	1.75	0.32	-1.71	2.39 *	-0.06	-0.700	-0.002	-0.01	0.86	0.41
5 CISA HTEM 10212 x 5 CISA HTEM 10211	1.40	0.28	-0.47	1.12	0.46	0.01	0.02	0.02	-0.42	0.37
5 CISA HTEM 10212 x 46 IBWSN 1005	2.19	-0.48	4.63 **	-5.43 **	0.13	0.99	0.02	0.03	-2.73 *	-0.62
5 CISA HTEM 10212 x DBW 14	1.22	0.46	-3.014 *	4.37 **	-0.58	-1.61	-0.02	-0.02	2.60 *	0.58
GW 322 x 3 SATYN 9402	-1.80	-2.46 **	-2.19	-4.44 **	-0.37	-0.50	-0.06 **	-0.08 **	-1.38	-3.15 **
GW 322 x K9107	0.85	-2.03 **	-2.38	-3.34 **	-0.11	-0.86	-0.04 *	-0.05 *	-1.96	-2.60 **
GW 322 x HD 2967	-0.40	-0.69	2.05	-3.89 **	-0.08	0.54	0.00	0.00	-1.39	-0.88
GW 322 x RAJ 1972	2.95	-0.42	0.66	-1.60	0.11	0.36	0.00	0.00	-1.19	-0.54
GW 322 x PBW 343	2.78	0.14	-0.02	0.36	-0.61	-0.38	-0.01	-0.02	1.37	0.18
GW 322 x 5 CISA HTEM 10211	6.06 **	0.52	0.83	0.59	0.00	-0.10	0.01	0.02	0.26	0.67
GW 322 x 46 IBWSN 1005	-3.72 *	-0.56	-2.89 *	0.99	0.11	1.07	-0.03	-0.04	1.19	-0.71
GW 322 x DBW 14	2.99	1.02	2.75	0.58	-0.17	0.29	0.03	0.04	0.34	1.31

3 SATYN 9402 x K9107	1.12	2.17 **	2.30	2.94 *	0.16	0.25	0.05 **	0.06 *	0.82	2.78 **
Cross	Thousand grain weight	Grain yield	Biomass	Harvest index	Grain protein content	Nitrogen harvest index	Total nitrogen uptake	Nitrogen uptake efficiency	Nitrogen utilization efficiency	Nitrogen use efficiency
3 SATYN 9402 x HD 2967	1.11	2.26 **	3.00 *	2.43 *	0.18	0.49	0.06 **	0.07 **	0.87	2.89 **
3 SATYN 9402 x RAJ 1972	5.6 **	-0.36	0.71	-1.49	-0.08	0.35	-0.01	-0.01	-0.35	-0.46
3 SATYN 9402 x PBW 343	-2.91	0.88	3.56 *	-1.00	0.05	0.80	0.03	0.04	0.09	1.12
3 SATYN x 5 CISA HTEM 10211	1.52	1.20 *	0.11	2.83 *	0.54	1.69	0.02	0.03	1.35	1.540 *
3 SATYN 9402 x 46 IBWSN 1005	5.19 **	1.60 **	0.67	3.11 **	0.41	1.65	0.03	0.04	1.26	2.052 **
3 SATYN 9402 x DBW 14	4.18 **	4.28 **	3.63 *	7.28 **	0.54	2.06 *	0.09 **	0.12 **	3.06 **	5.49 **
K9107 x HD 2967	1.90	-0.45	-0.39	-0.88	-0.19	-0.03	-0.02	-0.02	0.04	-0.57
K9107 x RAJ 1972	1.28	0.40	2.32	-0.96	0.32	0.86	0.02	0.03	-0.49	0.52
K9107 x PBW 343	-0.56	0.29	-0.26	1.18	0.39	1.49	0.001	0.00	0.57	0.37
K9107 x 5 CISA HTEM 10211	-1.64	0.05	-0.28	0.27	-0.19	-0.12	-0.01	-0.01	0.75	0.06
K910746 x IBWSN 1005	-2.48	-0.09	0.85	-1.20	0.02	0.46	-0.001	0.002	-0.30	-0.11
K9107 x DBW 14	-4.34 **	1.25 *	-0.21	3.89 **	-0.39	-0.08	0.004	0.009	2.85 **	1.60 *
HD 2967 x RAJ 1972	-0.60	-0.003	-1.52	1.01	0.20	0.63	-0.01	-0.01	0.68	-0.004
HD 2967 x PBW 343	0.56	0.02	-1.13	1.00	-0.13	0.52	-0.02	-0.02	1.31	0.03
HD 2967 x 5 CISA HTEM 10211	-1.53	0.09	-1.62	1.59	-0.04	-0.20	-0.01	-0.01	0.98	0.11
HD 2967 x 46 IBWSN 1005	2.80	2.35 **	1.25	4.67 **	0.40	0.40	0.050 *	0.06 *	1.41	3.00 **
HD 2967 x DBW 14	0.80	1.52 **	3.94 **	0.34	0.28	0.80	0.06 **	0.07 **	-0.11	1.94 **
RAJ 1972 x PBW 343	-2.07	0.42	-0.20	1.28	0.05	-0.25	0.01	0.01	0.54	0.53
RAJ 1972 x 5 CISA HTEM 10211	-4.74 **	0.12	5.29 **	-3.45 **	-0.15	-0.52	0.04	0.04	-2.03	0.15
RAJ 1972 x 46 IBWSN 1005	-0.72	-0.17	0.29	-1.19	0.08	-0.43	0.01	0.01	-0.83	-0.22
RAJ 1972 x DBW 14	0.60	0.30	-0.75	1.55	0.04	0.04	0.01	0.01	0.49	0.39
PBW 343 x 5 CISA HTEM 10211	2.25	-0.23	-1.86	0.91	-0.17	-0.76	-0.01	-0.02	0.46	-0.30
PBW 343 x 46 IBWSN 1005	1.91	-0.87	-0.92	-1.90	-0.27	-1.43	-0.02	-0.02	-1.18	-1.11
PBW 343 x DBW 14	1.28	0.93	2.89 *	0.34	-0.33	-0.66	0.03	0.04	0.13	1.20
5 CISA HTEM 10211 x 46 IBWSN 1005	-1.57	-1.21 *	2.66	-5.63 **	-0.03	-0.91	0.01	0.02	-3.39 **	-1.55 *
5 CISA HTEM 10211 x DBW 14	-1.93	-0.32	4.95 **	-4.19 **	0.01	0.43	0.04	0.05	-2.83 **	-0.41
46 IBWSN 1005 x DBW 14	-0.82	0.39	-1.72	2.67 *	-1.11 **	-1.15	-0.03	-0.04	3.72 **	0.50
Sij-Sik 95%	4.46	1.60	4.05	3.36	1.22	2.85	0.06	0.07	3.11	2.05
Sij-Sik 99%	5.89	2.11	5.34	4.44	1.61	3.76	0.08	0.10	4.10	2.71
Sij-Skm 95%	4.28	1.54	3.89	3.23	1.18	2.74	0.05	0.07	2.99	1.97
Sij-Skm 99%	5.66	2.03	5.13	4.27	1.55	3.62	0.07	0.09	3.94	2.60

Specific combining ability effects of the 66 single crosses

Estimate of *sca* effects of the sixty-six diallele crosses for morpho-physiological, yield, yield attributes, NUE and its related traits are shown in Table 3. Among sixty-six single crosses, the six cross combinations namely, 3 SATYN 9402 x K9107, 3 SATYN 9402 x HD 2967, 3 SATYN 9402 x 46 IBWSN 1005, 3 SATYN 9402 x DBW 14, HD 2967 x 46 IBWSN 1005 and WH 1022 x K 9107 found to be the best specific combiners for yield and NUE. These cross combinations also exhibited high *perse* performance. Previous researchers, Khan *et al.,* (2010), Farshadfar *et al.,* (2013), and Ahmad *et al.,* (2014) also found specific cross-combinations for different NUE component characteristics. Crosses with high mean and *sca* effects are more likely to exhibit transgressive segregation in self-pollinated crops such as wheat, where pure line breeding is cardinal (Ahmad *et al.,* 2014 and Singh *et al.,* 2003). Singh and Chatrath (1992) indicated that if the desirable characteristics are controlled by non-additive gene effects in autogamous crops, the selection should be delayed to subsequent generations. This findings in the inference that transgressive segregants which are potential can be acquired from subsequent generations as proposed by various researchers including Nour *et al.,* (2011), Khaled and Sayem (2014) and Kose *et al.,* (2017).

The NUE parents namely, 3 SATYN 9402, K9107, HD 2967 and 46 IBWSN 1005 found to best general combiner among twelve parents for important traits like grain yield, harvest index, nitrogen utilization efficiency and nitrogen use efficiency. The crosses namely 3 SATYN 9402 x K9107, 3 SATYN 9402 x HD 2967, 3 SATYN 9402 x 46 IBWSN 1005, 3 SATYN 9402 x DBW 14, HD 2967 x 46 IBWSN 1005 and WH 1022 x K 9107 found to be the best specific combiners for yield and Nitrogen use efficiency. Therefore Parents with good general combining ability (GCA) may be employed in recombination breeding while F_1s with specific combining ability (SCA) effects may be further advanced in selecting high NUE segregants with care in subsequent segregating generations under low-N conditions.

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