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RESEARCH ARTICLE
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Stability Analysis for Yield and Yield Contributing Traits in Wheat *(Triticum aestivum* L.)

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ABSTRACT

Experiments were conducted during the 2022-23 and 2023-24 *Rabi* seasons at three locations, Line x Tester mating design was used to assess the stability of 67 wheat genotypes for yield and related traits. In Phase I (first stage of the experiment) was carried out to generate forty-five F_1 hybrids by crossing fifteen lines with three testers. In Phase II (second stage of the experiment) was conducted by multilocational trial which involved three locations (one in India and two in Nigeria) using Randomized Complete Block Design (RCBD) with three replications. Standard agronomic practices were followed and data obtained were analyzed using the Eberhart and Russell statistical procedures. The results observed that, there was no stable genotype for all traits. However, some genotypes like DH-3086X PBW-343 and DBW-222X PBW ZN1 revealed high yield with moderate stability for grain yield/plant and other yield-related traits. DBW-173 and PBW ZN1 showed the highest stability with moderate yield. For chlorophyll content, the stable genotypes were HD-3721 X PBW-343, PBW-550X PBW-343, and CSW-18. Regarding protein content, DBW-187 and BORLAUG-100 were the most stable and high-performing. Therefore, selection of stable and high-yielding genotypes is reliable and beneficial for genotypes like DBW-173; PBW ZN1 (for grain yield); HD-3721 X PBW-343; PBW-550X PBW-343; CSW-18 (for chlorophyll content); DBW-187 and BORLAUG-100 (for protein content) for wheat improvement across the locations.

Keywords: Stability analysis, Genotype, Yield contributing trait, Yield.

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INTRODUCTION

Wheat (*Triticum aestivum* L.), as a member of the Poaceae family, is an allohexaploid species with 21 chromosome pairs arranged into three subgenomes: A, B, and D, with a genome composition of BBAADD and 2n = 6x = 42 (bread wheat) (Chaudhary et al., 2023; Divya et al., 2024). It originated through natural hybridization between Emmer wheat (AABB) (*Triticum dicoccon*), known as "farro," and Goat grass (DD) (*Aegilops tauschii*), referred to as hard grass (Kiranakumara et al., 2024).

Wheat is a self-pollinated species with a spike-type inflorescence. It contains three anthers attached to the base by thin filaments and enclosed by bract-like structures called lemma and palea, which surround the fruit known as the caryopsis (Tayebeh et al., 2022). The optimal temperatures for wheat growth are 20-25°C for germination, 16-20°C for tillering, and 20-23°C for grain formation (Tayebeh et al., 2022).

Mechanisms of Stability in Wheat

Some genetic and physiological mechanisms in wheat aids its stability and adaptability to many environmental stresses like some specific genes that were activated under stress conditions (encoding proteins) (Siddhi et al., 2018). Heat shock proteins (HSPs) also help in the protection of cellular proteins from denaturation under heat stress (Sadhu et al., 2024). Antioxidant genes are responsible for the synthesis of antioxidant enzymes like superoxide dismutase (SOD), catalase, and peroxidases that help in scavenging reactive oxygen species (ROS) produced under stress (Tanin et al., 2022).

Physiological mechanisms (homeostasis) for stability and adaptability involves osmotic adjustment such as accumulation of compatible solutes like proline, sugars, and polyols in response to drought or salt stress (Ghafoor et al., 2024).

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Yield and Stability

The concept of yield and yield components in wheat genotypes, as cited by Verma et al. (2021), emphasizes that the primary goal of most breeding programs is to identify genetically superior genotypes and if this superiority is genetic, the genotype will consistently reproduce its value across different environments. However, if the value is solely environmental, the genotype will not maintain its performance (Osman et al., 2022).

Yield per hectare is a key factor in determining the commercial acceptability of wheat varieties in developing countries (Kumar et al., 2018; Reckling et al., 2021). The relationship between yield and yield-related traits is important, as it enables more efficient selection for the simultaneous improvement of one or more yield-influencing component (Omrani et al., 2022a; Fellahi et al., 2013). Understanding this relationship aids in selecting suitable parents and crosses for the commercial success of conventional breeding programs, as crop yield is the result of all individual yield components working together, each contributing small cumulative effects on the overall yield (Kumar et al., 2022; Lee et al., 2023).

Stability analysis is utilized to assess the level of genetic determination (DGD) for sustainable crop improvement and environmentally friendly breeding programs (Bouchareb & Guendouz, 2022). Evaluation of potential genotypes under various environmental conditions (stability analysis) is a crucial and final step in most applied plant breeding programs (Siddhi et al., 2018; Ghafoor et al., 2024).

Current Challenges and Potential Solutions

Despite the rapid and consistent population growth in India and Nigeria and efforts to produce commercial hybrid seeds have been attempted several to many times using various sterility induction techniques which include genetic male sterility, cytoplasmic genetic male sterility, and chemical hybridizing agents for wheat improvement (Mohamed et al., 2024). However, these efforts have had limited practical relevance due to polyploidy nature and the technical complexities involved in large-scale hybrid seed production in wheat (Ahmed et al., 2023).

Wheat production faces several challenges that affect its yield and quality, such as salinity, heat stress, diseases/pests and insufficient breeding information, including stability analysis; genetic variability and adaptability (Popović et al., 2020; Sujitha et al., 2024).

Most existing and previous studies on stability were carried out in either India or Nigeria, but not both, leaving a significant gap between these two distinct agro-ecological zones. The present investigation is potential to mitigate some challenges faces by wheat farmers often used unsuitable genotypes in inappropriate environments as reported by Enyew et al. (2021) and Mullualem et al. (2024) stability analysis is an eco-friendly, non-transgenic breeding approach that offers vital information for the inheritance patterns of yield-related traits.

Research was designed to assess the stability of 67 wheat genotypes for yield and related traits to improve wheat production, ensure resilience against environmental stresses and contribute to sustainable agricultural practices that can meet the demands of growing population.

MATERIALS & METHODS

Experimental Material and Site

The experimental materials consisted of 67 wheat genotypes, including fifteen lines, three testers, four checks, and forty-five F_1 hybrids derived from crossing of fifteen lines with three testers. Some materials includes; breeder's kit was used; SPAD (Soil Plant Analysis Development) handheld meter, meter rule, electric weighing balance (Compax-Cx-600), seed counting machine, digestion apparatus, sodium hydroxide, hydrochloric acid and others.

Table 1 summarized the sources and status of genotypes used in the experiment; while Table 2 provides comparative weather report for the 2023-2024 *Rabi* season across three locations Borno State (Nigeria), Kebbi State (Nigeria) and Phagwara (Punjab State, India) showing variations in temperature (high and low), rainfall (in mm), and relative humidity (RH in %) for each month.

Geographical information of three locations used for the experiment presented as; location one (Fig. 1) was teaching and research farm, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara Punjab India, located between latitude 31.2245° N and longitude 75.7711° E on an altitude of about 243m above the sea level with annual rainfall of 527.1mm (MAFW, 2023).

Location two (Fig. 2) was teaching and research farm of Kebbi State University of Science and Technology Aliero, Kebbi State (KSUSTA), Nigeria, located in the Sudan Savanna agro-ecological zone of Nigeria between latitude 13^0 08 N and longitude 5^0 15 E on an altitude of about 250 m above sea level with annual rainfall ranges from 1500-1700mm. While third location (Fig. 3) Lake Chad research Institute, Borno State Nigeria, located between latitude 11.8467°N and longitude 13.1571°E, on an altitude of about 325m above sea level with annual rainfall ranges from 900-1500mm (FMARD, 2023).

Methods

In phase I (2022-23 *Rabi* season), Augmented Design was used to generate forty-five (45) F_1s hybrids by crossing 15 lines with three testers. In phase II, the experimental materials were evaluated at three locations using Randomized Complete Block Design with three replications during the *Rabi* 2023-24 season. Each plot consisted of three rows, each 3m in length, with an inter-row spacing of 22.5cm. Standard agronomic practices were followed as per the recommended guidelines.

Experiment was conducted at three locations; first location was the teaching and research farm, Department of Genetics and Plant Breeding, Lovely Professional University, Phagwara, Punjab, India; the second at the teaching and research farm of Kebbi State University of Science and Technology, Aliero, Kebbi State, Nigeria and the third at the Lake Chad Wheat Research Institute, Borno State, Nigeria.

Table 1: List of parents and four checks (Sources and Status)

Sr. No.	Genotype	Source of genotypes	Status (released variety/advanced line etc.)
1	BHU 25	Banaras Hindu University (BHU)	Released Variety
2	WB-02	Private Sector (West Bengal)	Released Variety
3	BHU 31	Banaras Hindu University (BHU)	Released Variety
4	HD 3721	ICAR-IIWBR	Released Variety
5	PBW 725	Punjab Agricultural University (PAU)	Released Variety
6	CRD GEHNU1	ICAR-IIWBR/Collaborator Institute	Released Variety
7	PBW 550	Punjab Agricultural University (PAU)	Released Variety
8	PBW 677	Punjab Agricultural University (PAU)	Released Variety
9	PBW 822	Punjab Agricultural University (PAU)	Released Variety
10	HD 3117	ICAR-IIWBR	Released Variety
11	DBW 173	ICAR-IIWBR	Released Variety
12	HD 3086	ICAR-IIWBR	Released Variety
13	DBW 222	ICAR-IIWBR	Released Variety
14	CSW 18	ICAR-IIWBR	Released Variety
15	PBW 757	Punjab Agricultural University (PAU)	Released Variety
16	PBW ZN1 (tester1)	Punjab Agricultural University (PAU)	Released Variety
17	PBW 343 (tester2)	Punjab Agricultural University (PAU)	Released Variety
18	HD 3326(tester3)	ICAR-IIWBR	Released Variety
19	HD 2967 (check1)	ICAR-IIWBR	Released Variety
20	DBW 187 (check2)	ICAR-IIWBR	Released Variety
21	Norman (check3)	CIMMYT/ICAR Collaborations	Released Variety
22	Borlaug-100(check4)	CIMMYT/ICAR Collaborations	Released Variety

Table 2: Weather report 2023-2024 seasons across three locations

Month	High Temp (°C)	Low Temp (°C)	Rainfall (mm)	R. H. (%)	High Temp (°C)	Low Temp (°C)	Rainfall (mm)	R. H. (%)	High Temp (°C)	Low Temp (°C)
October	36	23	15	45	37.4	25.5	36.3	58	32	20
November	34	18	0	25	37.1	22.4	0	29	27	15
December	31	15	0	20	34.4	18.1	0	20	21	10
Rabi season 2024										
January	31	14	0	15	34.7	17.1	0	20	19	8
February	34	17	0.2	14	37.8	19.8	0.53	18	23	10
March	38	20	1	17	40.8	23.3	4.9	24	29	15
April	41	24	3	21	42.3	27	24.2	36	36	21
May	40	27	13.5	35	41.3	29.8	75.5	49	40	26
June	37	26	63	50	38.8	28.8	94.9	58	41	29
July	33	24	115	65	35.4	26.3	170.2	70	36	28
August	31	23	198	75	32.8	24.4	179.1	79	34	26
September	33	24	80	68	34.7	24.9	151.1	76	34	24

Source: Nigerian Meteorological Agency (Nimet) report for the two State Source: Punjab Agricultural University of Agriculture

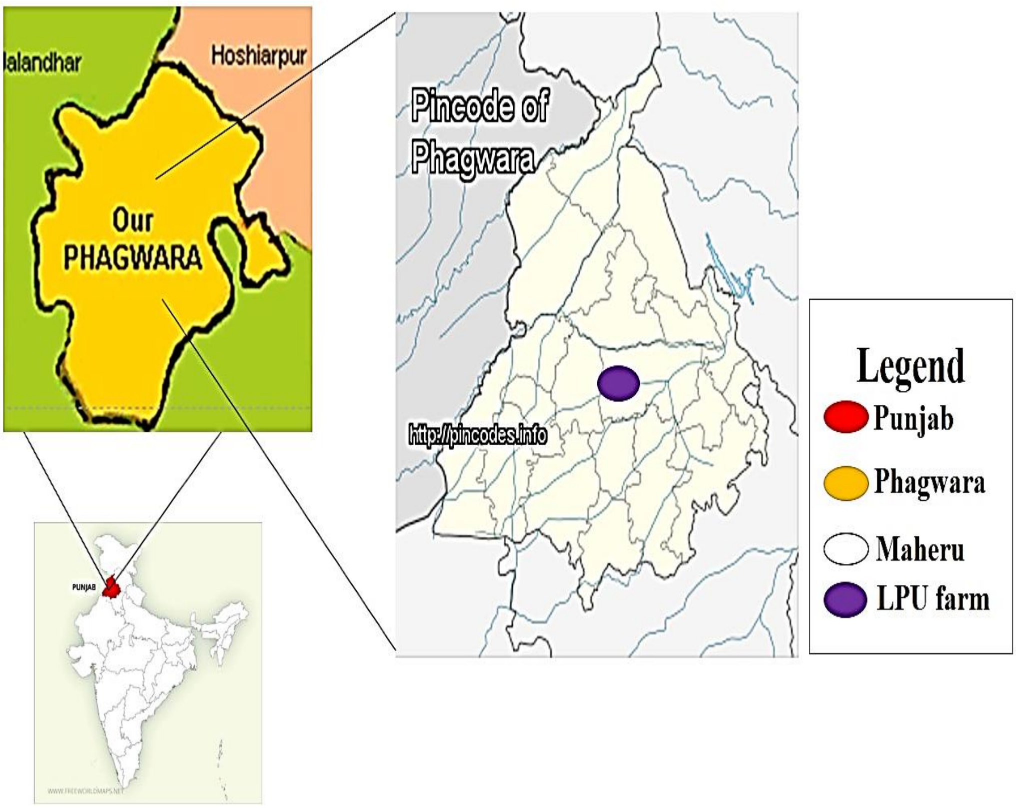

Fig. 1: The experimental site in Lovely Kebbi Professional University, Phagwara (LPU), India Technology Aliero (KSUSTA).

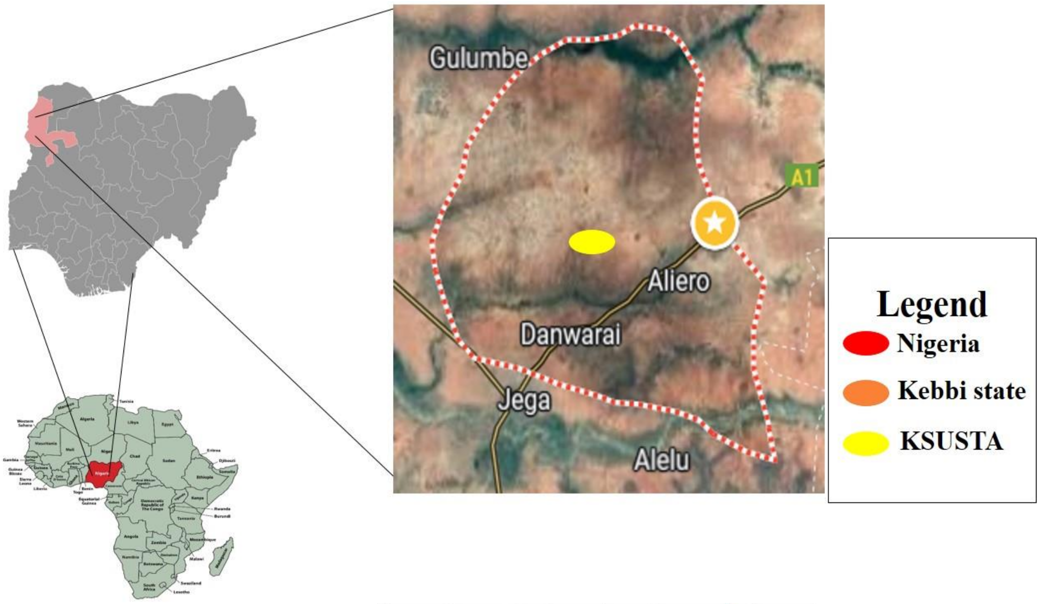

Fig. 2: The experimental site in State University of Science and Nigeria (Location II).

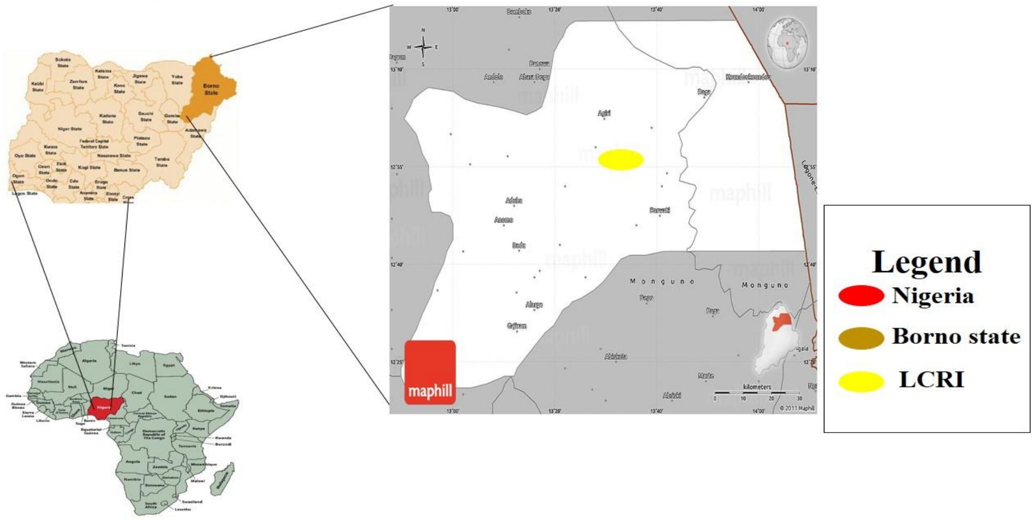

Fig. 3: The experimental site Lake Chad Research Institute (LCRI) in Kukawa, Borno State Nigeria (Location III).

The collected data on quantitative and qualitative traits were subjected to statistical analysis using Eberhart and Russell's (1966) method, using three stability parameters namely; mean performance; regression coefficient and deviation from regression (mean, bi and S^2di).

Statistical Analysis

Eberhart and Russell (1966) described the following procedure for stability analysis:

(i). test of mean yield of genotypes using 't' test.

$$t = {(\mu i - \mu)}/{SE(x)}$$

$$SE\,(x) = \sqrt{\frac{Pooled\ deviation\ MS}{Number\ of\ environments - 1}}$$

μi = mean yield over all environment

μ = general mean

(ii) Regression on environmental index 'F' test.

$$F = {MS3}/{MS4}$$

(iii) bi (deviation) 't' test.

t = (bi – 1) and S.E. (b) at v (n-2) d. f.

Where,

$$S.E.\,(b) = \sqrt{\frac{Pooled\ deviation\ MS}{\sum_{j=1}^{n} I2j}}$$

Individual genotype tested using the 'F' test.

$$F = {1}/{(n-1)} \sum_{j=1}^{n} \sigma^2_{ij} / \text{MSS}$$

RESULTS & DISCUSSION

Quantitative Parameters

Stability analysis of quantitative traits in wheat focuses on identifying varieties that perform consistently across different environments. It helps breeders select wheat lines that are not only high-yielding but also stable in yield and quality under varying conditions (Pour-Aboughadareh et al., 2022). Ismail et al. (2023) reported that, evaluation of traits like number of productive tillers, harvest index, biological yield, grains yield per plant, 1000 grain yield etc breeder can assess adaptability and stability analysis of wheat varieties that can withstand environmental fluctuations such as drought, heat, and soil variability, contributing to more reliable and sustainable wheat production.

Eberhart and Russell (1966) reported three parameters that helps to measure stability among population, namely; average yield performance, regression coefficient (bi) and deviation from the regression (S^2di). The model also described, bi value around 1 indicates average stability, bi

Table 3: Analysis of Variance (ANOVA) and estimates of components of variance for pooled data over three locations for 16 traits of 67 wheat genotypes

TRAIT	Location (L) variance	Replication (R) variance	LXR variance	Genotype (E) variance	GXL variance	Error variance
d.f.	2	2	4	66	132	124
DH	0.64	16.71**	27.81**	468.83**	10.73	0.65
DM	12.79*	32.47**	15.81	204.92**	19.24*	12.79**
FLA	0.54	42.41**	22.56	219.53	9.68	0.54
GFP	1.85	18.04**	41.96**	112.13	68.08**	1.85
PH	3.00	16.37**	5.68	259.54**	7.15	3.01
NPT	0.64	6.768**	2.85	11.15	2.27	0.65
CLC	4.07	1.07	3.56	228.97	5.52	4.08
NS/S	1.37	3.96	7.47	40.5	17.91	1.37
SL	0.44	5.78	1.16	9.79	1.34	0.45
NG/S	29.86**	11.97**	37.96	162.36**	3.61	29.87**
GW/S	0.38	11.66**	1.71	0.43	0.04	0.38
1000GWT	21.74**	3.87	33.12**	211.72	6.98	21.74*
BY	3.22	24.55	15.94	142.59**	17.70*	3.22
HNDX	35.34**	1.21	9.54	393.23**	8.9	35.34**
PR CT	0.73	5.66	3.06	1.32	0.14	0.74
GY/P	53.08**	5.69*	19.23*	147.42**	9.27	53.08**

"*" and "**" for 5% and 1% Level of Significance and Days to 50% heading (DH), Plant height (PH) (cm), Days to maturity (DM), Grain filling period (GFP), Spike length (SL) (cm), Flag leaf area (FLA) (cm^2), Chlorophyll content (CLC), Protein content (PC) (%), Number of spikelet/spike (NS/S) (cm), Number of productive tiller (NPT), Number of grain per spike (NGS), Grain weight/spike (GW/S) (g), 1000-grain weight (g) (TGW), Biomass yield (BY) (g), Harvest index (HI %) and Grain yield/plant (GY/P) (g).

<1 indicates stability (under both the favorable and unfavorable environmental conditions) and bi >1 indicates stability (under favorable environmental conditions only) and deviation from the regression (S^2di), lower S^2di values indicates higher stability (very little variation across different locations).

Number of productive tillers (Table 4) are controlled by specific genes that influence tiller initiation and development (Askander et al., 2021). Results on number of productive tillers indicated that, high stability observed in genotypes NORMAN (-0.03) and BHU-31 X PBW-343 (0.13) while low stability recorded in genotypes DBW-187 and DH-3086X HD-3326 (bi 2.61 and 2.61, respectively). Similar results reported by Kshatri et al. (2021), Tayebeh et al. (2022) and Ghafoor et al. (2024) that the environmental differences significantly affect performance for yield related traits such as number of productive tiller, plant height and 1000 grain yield in wheat (Table 3).

Biological yield (g) (Table 4), we observed high biological yield and stability in genotypes DBW-173X HD-3326 (Mean 65.61, bi 1.36, S^2di 1.68) and lowest stability and yield recorded in DBW-173 (32.63) and CSW-18 (bi 8.85), PBW-550X PBW ZN1 bi 8.60. The finding was in conformity with research results conducted by Pour-Aboughadareh et al. (2022) showed that environments (E), hybrids (H) and their interaction (HEI) for most of traits recorded significant difference except number of productive tillers and grain yield per plant, this may be as a result of genetic and environmental variation.

Harvest index (%) (Table 4), considered as ratio between grain yield and total biological yield (Enyew et al., 2021; Mullualem et al., 2024). Results observed that, genotypes DH-3086X PBW-343 (S^2di -1.29) and PBW-822X PBW ZN1 (S^2di -1.33) showed good stability and can be best candidates in diverse environments (additive gene effects). While HD-3721 X HD-3326 (S^2di 39.02) and PWB-725 X PBW ZN1 (S^2di 42.57) revealed high variability (not stable). The results also agreed with researches independently conducted by Siddhi et al. (2018) and Omrani et al. (2022b) observed significant differences in stability analysis using 11 traits among twelve genotypes, Ratan and CG 1029 recorded as the most stable genotypes.

Gain yield per plant (g) (Table 4) revealed that, genotypes HD-3326 (S^2di 0.93), DBW-173 (S^2di 1.05), BHU-25 (S^2di 1.45) and BHU-25X HD-3326 (S^2di 1.81) scored the highest stability across the three environments, while the least stability was recorded in BHU-25 X HD-3326 (S^2di 20.80). Similar results were obtained by Gowda et al. (2010) and Maeng (2019). They reported that some wheat genotypes were highly stable with moderate mean performance, this results in high yield and stable performance in the advance generation. High stable grain weight per spike (g) (Fig. 4) were observed in genotypes PBW-550, PBW-550 X PBW-343, WB-02, CSW-18 X PBW ZN1, DH-3086 X PBW ZN1 and NORMAN and least for stability were observed in BHU-31 X PBW-343 and HD-3721. This is in conformity with research conducted by Darwish et al. (2024), the analyses showed that G6 was high-yielding and adaptive and stable. Spike length (cm) (Fig. 5 revealed that, genotypes BHU-25 X PBW ZN1, DBW-222 X DH-3326 and NORMAN were highly stabled across all locations while lowest stability observed in genotypes PBW ZN1 and HD-3721. The findings were commemorated by researches conducted independently by Najafi-Mirak et al. (2021) recorded genotypes NEST-17-04 and NEST-17-37 were found to be promising for optimum yield over varying environments for number of spikelets per spike and spike length. Al-Sayaydeh et al. (2023) and Darwish et al. (2024) observed that AMMI analysis of stability for yield-related traits showed significant variation due to the genotype effect for KA, KL, KC, and KL, KW, whereas the variation in KW was mainly attributed to environmental factors.

Number of grain per spike (Fig. 6) indicated high stability in genotypes CSW-18XHD-3326, BHU-31 X PBW-343, DBW-222X HD-3326, BHU-25 X HD-3326, HD-2967 and NORMAN (hierarchically). However, least stability recorded PBW-822 and CRD GEHNU1. Similar results reported by Sujitha et al. (2024) recorded the two genotypes for good adaptability and stability 53 genotypes evaluated. 1000 Grain weight (g) (Fig. 7)

Table 4: Stability analysis on number of productive tillers, biological yield, harvest index and Grain yield per plant from three locations using 67 wheat genotypes during 2022-2023 and 2023-2024 *Rabi* seasons (Nov.-April)

SN	Genotype	No. of productive tiller			Biological yield (g)			Harvest index (%)			Grain yield per plant (g)		
		*		*	*		*	*		*	*		*
SN	Genotypes	Mean	bi	S^2di	Mean	Bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
1	HD-2967	4.49	1.12	0.83	51.08	0.15	23.14	47.53	1.47	32.74	34.67	-2.03	0.84
2	DBW-187	5.03	2.02	0.36	52.45	0.55	31.50	48.87	0.62	-0.15	37.38	7.08	4.99
3	NORMAN	4.98	-0.24	-0.03	52.13	0.68	19.04	46.10	1.44	10.35	33.96	-2.38	-0.40
4	BORLAUG-100	6.59	0.84	0.38	56.06	0.55	3.71	48.99	1.04	17.61	39.65	7.75	3.38
5	BHU-25	4.16	0.59	0.36	51.07	0.86	23.66	47.00	1.56	1.32	33.31	0.90	1.59
6	HD-3117	4.62	0.77	0.28	49.96	1.18	23.38	44.58	0.78	31.84	34.88	4.92	16.58
7	BHU-25 X PBW ZN1	8.27	1.64	0.84	61.24	1.56	20.29	52.74	-0.77	5.42	42.83	-1.94	3.41
8	BHU-25 X PBW-343	7.96	1.26	-0.02	63.10	1.09	19.72	55.87	-0.25	23.53	44.14	-3.06	7.10
9	BHU-25 X HD-3326	7.86	1.03	0.85	63.38	0.10	0.84	56.33	1.13	5.59	44.13	-4.52	20.80
10	DBW-173	4.28	0.56	0.41	52.71	1.20	2.31	46.74	1.39	4.54	32.63	0.24	1.81
11	DBW-173X PBW ZN1	7.59	1.60	0.23	62.71	1.13	1.21	57.62	0.07	4.44	43.28	-0.93	-0.71
12	DBW-173X PBW-343	9.06	1.07	0.62	63.62	1.26	6.29	57.65	0.54	10.98	48.70	8.80	16.24
13	DBW-173X HD-3326	8.15	1.07	0.18	65.61	1.36	1.68	58.84	0.35	0.90	49.85	4.71	7.85
14	DH-3086	5.01	2.34	-0.10	54.16	1.09	8.08	46.79	1.47	7.28	35.86	7.02	11.11
15	DH-3086X PBW ZN1	7.09	2.08	1.59	64.66	1.26	2.09	56.34	1.61	4.60	49.38	5.54	9.80
16	DH-3086X PBW-343	7.59	-0.20	3.63	64.14	1.05	3.36	58.78	1.12	-1.29	51.32	1.07	1.04
17	DH-3086X HD-3326	7.74	1.57	0.16	63.55	0.61	7.77	54.38	0.94	14.26	44.13	-2.69	4.59
18	DBW-222	5.70	1.16	1.01	60.42	2.22	21.64	48.51	1.81	7.59	41.42	5.84	26.55
19	DBW-222X PBW ZN1	9.48	0.97	-0.08	65.43	1.12	-1.26	57.55	0.05	8.75	50.04	0.99	1.69
20	DBW-222X PBW-343	8.56	0.66	0.84	64.15	2.07	18.52	57.52	0.80	-0.61	47.82	0.08	1.19
21	DBW-222X HD-3326	7.22	1.20	-0.06	64.72	1.07	2.34	53.83	-0.88	7.52	43.73	-2.86	15.12
22	CSW-18	5.28	1.86	0.34	55.33	1.44	-1.41	44.23	1.59	1.67	35.70	8.85	2.82
23	CSW-18XPBW ZN1	8.10	0.89	0.35	62.81	0.42	21.10	59.45	0.76	-1.52	46.99	-0.61	-0.51
24	CSW-18XPBW-343	8.32	1.26	2.05	64.27	0.84	0.31	59.03	0.53	0.16	48.95	3.05	38.74
25	CSW-18XHD-3326	7.88	1.42	1.47	64.77	0.65	16.34	56.52	1.05	9.67	44.05	-4.84	8.93
26	PBW-757	5.17	-0.200	0.33	52.30	1.07	5.78	48.38	1.71	3.02	35.93	0.24	1.81
27	PBW-757X PBW ZN1	8.43	0.72	1.58	64.41	1.06	13.97	57.14	1.59	3.79	49.17	3.09	19.83
28	PBW-757X PBW-343	7.67	-0.26	1.24	62.88	1.12	1.42	58.02	1.07	3.79	48.81	1.35	28.84
29	PBW-757X HD-3326	7.66	0.56	0.07	60.85	0.45	25.67	58.97	0.84	-0.32	44.35	1.33	8.56
30	BHU-31 X PBW ZN1	6.79	1.48	0.04	57.47	1.59	5.24	50.87	1.98	2.39	41.80	-3.77	13.93
31	BHU-31 X PBW-343	6.35	0.95	0.13	59.33	0.13	-1.60	53.43	0.62	5.56	39.58	-3.72	12.72
32	BHU-31 X HD-3326	6.65	1.76	0.10	63.14	1.30	-0.55	53.51	1.53	27.12	41.66	-0.19	-0.24
33	WB-02	5.58	-0.36	-0.05	55.35	0.80	-0.75	46.68	1.25	16.98	34.21	0.24	1.81
34	WB-02 X PBW ZN1	7.83	0.62	1.13	65.56	1.03	1.56	54.81	1.57	19.93	45.21	-0.23	0.19
35	WB-02 X PBW-343	7.40	2.01	0.60	60.18	1.11	48.93	54.75	0.77	26.98	42.16	0.22	20.99
36	WB-02 X HD-3326	6.71	2.61	1.52	63.55	0.13	11.12	51.17	-0.12	3.60	40.58	5.12	17.63
37	BHU-31	5.20	-0.01	0.51	53.38	0.92	19.07	48.55	1.39	4.50	35.27	0.24	1.81
38	BHU-31 X PBW ZN1	7.42	0.76	0.10	59.33	0.73	23.95	55.50	0.82	11.06	43.32	0.04	0.76
39	BHU-31 X PBW-343	7.39	2.06	0.26	58.38	0.89	18.32	55.83	2.29	4.25	41.55	-1.12	-1.42
40	BHU-31 X HD-3326	7.54	2.69	-0.06	58.91	0.83	96.03	55.99	0.58	9.45	44.84	4.48	16.34
41	HD-3721	4.49	0.49	-0.12	53.63	0.01	33.39	46.99	1.81	8.06	33.38	0.24	1.81
42	HD-3721 X PBW ZN1	7.95	2.44	-0.06	64.66	0.72	7.44	55.56	2.39	7.28	44.85	4.41	-0.19
43	HD-3721 X PBW-343	6.84	1.60	0.01	62.54	1.16	-1.85	54.23	0.02	0.25	42.24	-0.85	-0.57
44	HD-3721 X HD-3326	8.63	0.93	0.28	63.92	1.23	1.81	54.05	1.46	39.02	47.11	-0.64	-0.54
45	PWB-725	4.44	0.13	-0.02	53.20	0.91	24.26	47.40	0.93	6.70	34.24	1.41	1.41
46	PWB-725 X PBW ZN1	7.54	1.86	0.06	62.04	1.34	34.89	55.20	0.38	42.57	43.69	4.86	21.91
47	PWB-725 X PBW-343	7.62	2.04	0.42	64.24	0.13	23.83	53.89	1.03	9.23	42.37	-3.27	8.76
48	PWB-725 X HD-3326	8.33	1.01	-0.09	61.70	1.15	23.71	57.58	1.48	-1.53	45.95	-2.27	1.81
49	CRD GEHNU1	5.54	-0.12	0.19	57.29	2.49	93.12	46.79	1.56	19.03	40.98	8.46	20.84
50	CRDGEHNU1 X PBWZN1	8.42	2.00	0.81	65.15	0.60	0.07	55.66	0.72	1.49	44.76	-2.79	5.22
51	CRDGEHNU1 X PBW343	8.19	1.27	0.01	61.45	0.97	20.01	56.54	0.85	6.72	44.88	-0.37	-0.37
52	CRDGEHNU1 X HD-3326	7.37	0.73	0.21	60.67	0.26	45.22	55.31	1.43	27.22	41.93	-3.70	12.56
53	PBW-550	4.76	-0.69	0.20	56.49	0.80	0.55	49.96	1.69	4.28	36.36	0.24	1.81
54	PBW-550X PBW ZN1	7.93	-0.55	-0.03	61.85	0.99	32.08	57.49	1.43	1.70	46.52	8.60	2.24
55	PBW-550X PBW-343	8.48	0.69	1.06	64.36	1.39	0.40	55.05	0.94	2.52	46.23	-0.53	-0.40
56	PBW-550X HD-3326	8.37	0.73	0.86	64.01	1.20	27.31	56.29	1.04	1.62	46.80	0.50	2.87
57	PBW-677	5.07	0.10	0.36	55.09	0.89	42.87	46.78	1.52	1.95	34.53	0.24	1.81
58	PBW-677XPBW ZN1	7.99	1.48	0.88	59.81	0.68	37.80	56.75	0.43	8.25	40.76	-3.20	16.24
59	PBW-677XPBW-343	8.35	0.83	0.19	60.41	0.20	32.34	58.93	1.19	-0.37	48.07	4.17	-0.72
60	PBW-677XPBW-343	8.07	2.28	0.87	61.78	1.51	1.24	55.28	0.56	13.10	42.92	-2.34	2.70
61	PBW-822	4.62	0.43	1.04	50.38	0.86	41.59	44.75	0.96	4.34	35.17	4.81	19.94
62	PBW-822X PBW ZN1	9.07	0.38	1.11	65.25	1.54	2.43	59.43	0.94	-1.33	53.00	3.05	30.78
63	PBW-822X PBW-343	8.31	0.74	0.39	64.24	0.61	6.28	55.79	0.18	16.49	45.53	-3.15	2.42
64	PBW-822X HD-3326	8.32	1.15	-0.15	64.24	1.31	6.83	57.77	-0.35	1.74	46.47	0.38	2.41
65	PBW ZN1	4.89	0.57	0.09	53.74	1.92	20.54	45.55	1.81	9.48	35.58	0.24	1.81
66	PBW-343	5.56	0.25	0.44	55.79	1.63	94.81	45.64	0.49	11.61	35.69	-0.14	0.45
67	HD-3326	6.07	0.03	0.31	54.80	1.71	5.07	48.79	1.74	7.14	38.95	0.24	1.81
	Grand Mean:	6.24			56.78			49.17			40.24		
	SE±	0.06			1.17			0.48			0.32		
	C.D.1%:	1.08			2.97			1.25			0.83		

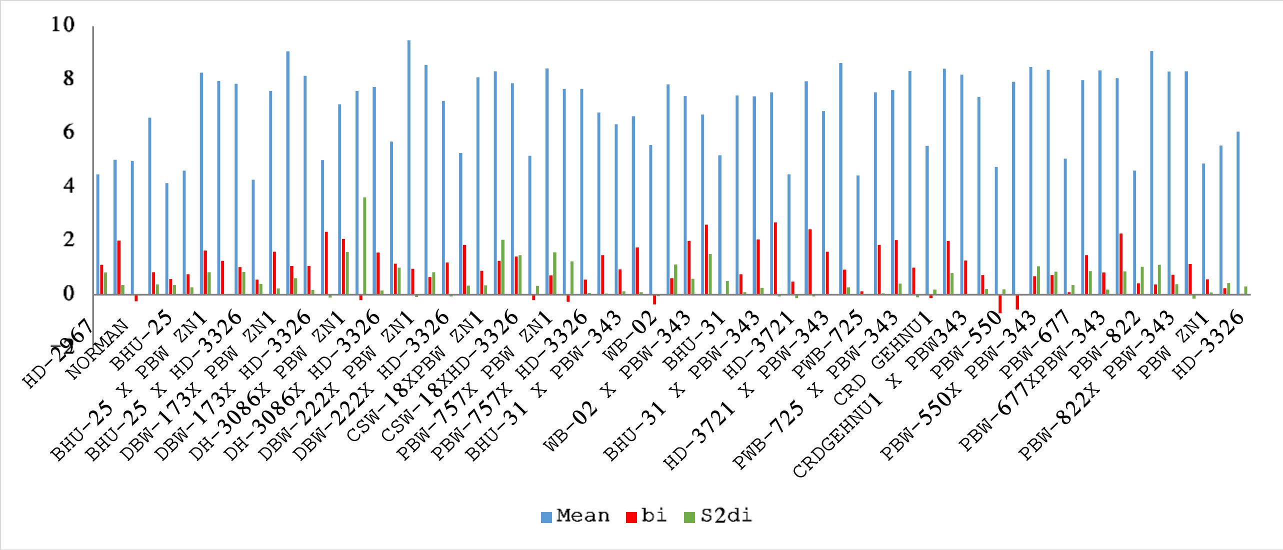

Fig. 4: Shows Grain weight per spike (g) using mean yield (blue), regression (red) and deviation from regression (green). bi value around 1 indicates average stability, bi < 1 indicates stability (under both the favorable and unfavorable conditions) and bi > 1 indicates stability (under favorable conditions only) and lower deviation from the regression (S^2di) indicates higher stability.

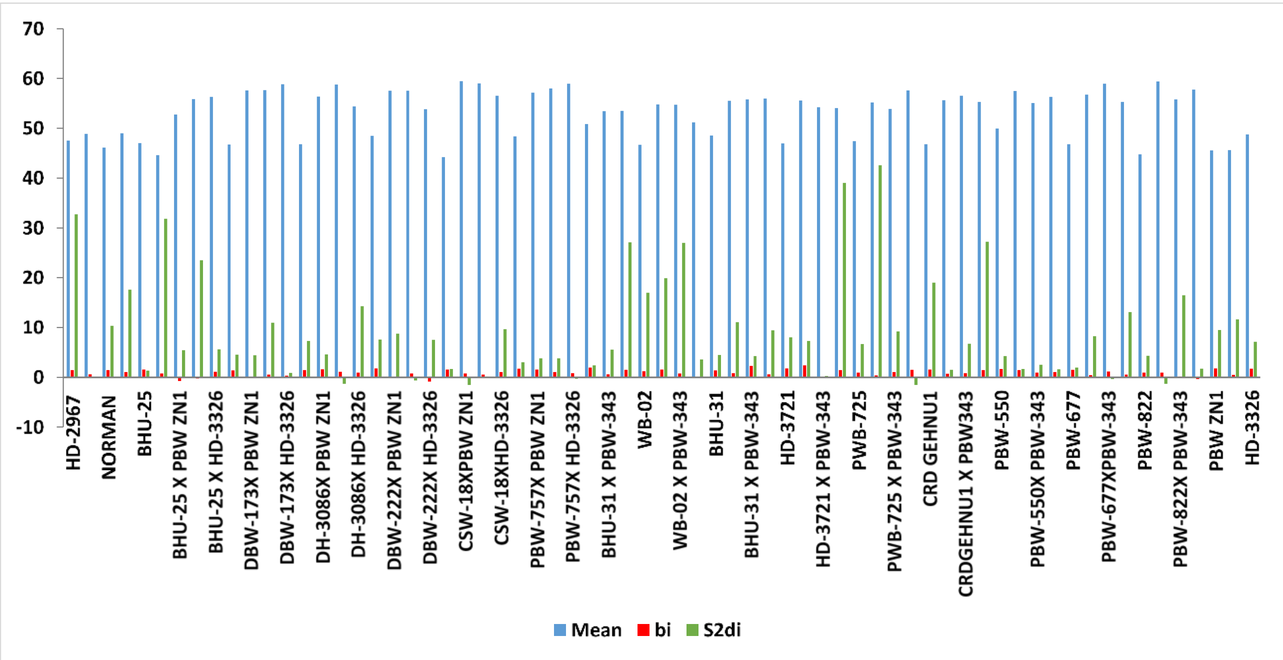

Fig. 5: Shows Spike length (cm) using mean yield (blue), regression (red) and deviation from regression (green). bi value around 1 indicates average stability, bi <1 indicates stability (under both the favorable and unfavorable conditions) and bi > 1 indicates stability (under favorable conditions only) and lower deviation from the regression (S^2di) indicates higher stability.

observed that, high stability recorded in genotype BUH-31, CRDGEHNU1, PBW-725 and HD-3086 X PBWZN1 with least regression (bi), deviation from the regression (S^2di) and high mean yield and lowest stability observed in HD-3721 AND PBWZN1 with highest regression (bi), deviation from the regression (S^2di) and high mean yield. The results have been supported by an experiment conducted by Jayalakshmi et al. (2024) found that among three locations, Gulbarga was the most favorable environment for the expression of 1000 grain weight and grain yield per plant.

Qualitative Parameters

Chlorophyll content (Table 5) the genes controlling chlorophyll content influenced by leaf senescence and affects the plant's photosynthetic capacity and overall yield (Patel et al., 2014). Results revealed that genotype PBW-757X PBW-343) recorded high stability with mean yield of (53.67) bi (2.01 (highly stable to less favorable conditions) and S^2di (-2.15. While genotype DBW-173 (Mean 41.46), bi 0.59 (average stability), indicating the preponderance of additive gene action. The results were supported by researches conducted independently by Saleem et al. (2015) and Kumar et al. (2020) stated that selection of genotypes for quality parameters is reliable, stable and suitable for quality improvement across different environments as stable genotypes are ideal for maximizing productivity. Protein content (%) (Table 5) is not directly linked to grain yield Jat et al. (2017) (Table 2).

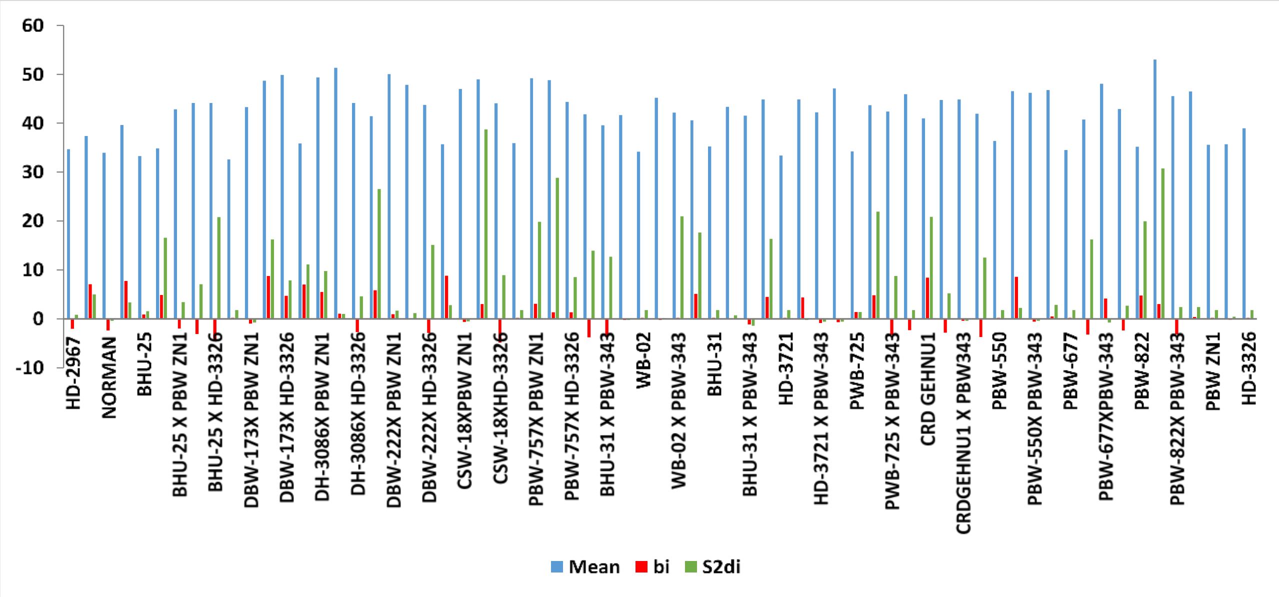

Fig. 6: Shows number of grain per spike using mean yield (blue), regression (red) and deviation from regression (green). bi value around 1 indicates average stability, bi < 1 indicates stability (under both the favorable and unfavorable conditions) and bi > 1 indicates stability (under favorable conditions only) and lower deviation from the regression (S^2di) indicates higher stability.

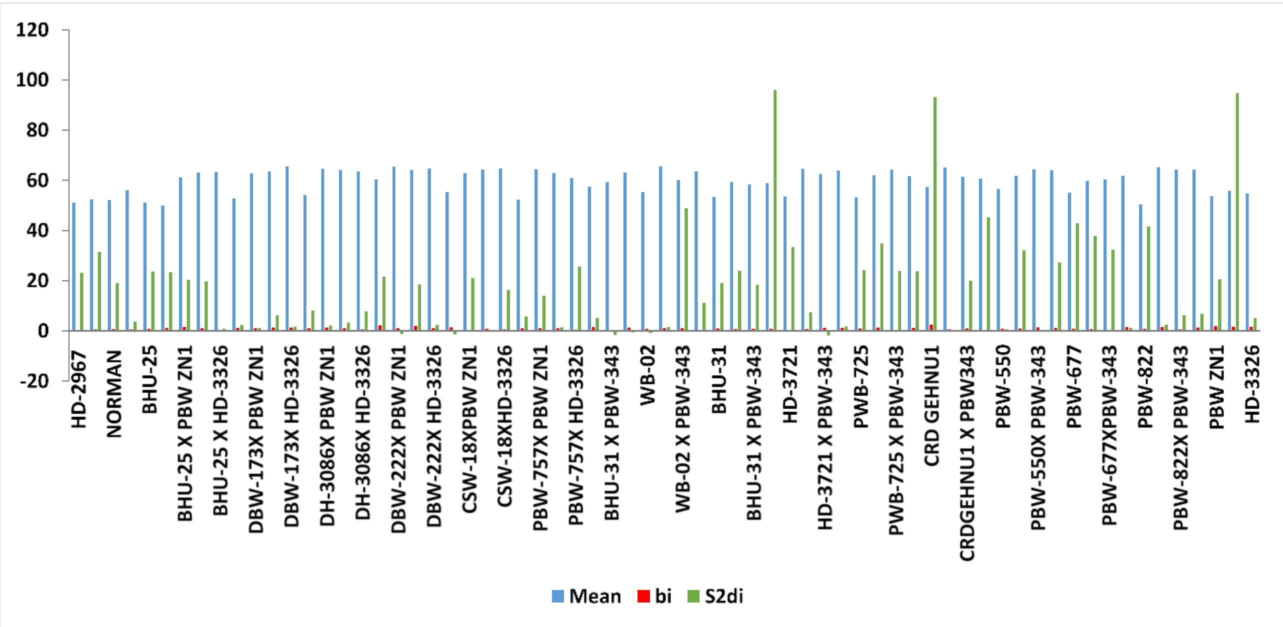

Fig. 7: Shows 1000 grain weight (g) using mean yield (blue), regression (red) and deviation from regression (green). bi value around 1 indicates average stability, bi < 1 indicates stability (under both the favorable and unfavorable conditions) and bi > 1 indicates stability (under favorable conditions only) and lower deviation from the regression (S^2di) indicates higher stability.

Results revealed that Genotype HD-3117 X PBW-343 (mean protein content (11.87%) indicating low variability, bi (-2.61) showing below-average responsiveness to environmental changes, S2di (-0.04) indicating stability. Genotype DBW-173X HD-3326 (mean protein content (12.53%, bi (12.25) showing high responsiveness to environmental changes and S^2di (0.60) indicating instability, similar results was reported by Sadhu et al. (2024).

Conclusion

Experiment concluded that, for grain yield per plant and other yield contributing traits genotypes DH-3086X PBW-343 and DBW-222X PBW ZN1 recorded high yield with moderate stability. However, highest stability with moderate yielding ability recorded in genotypes DBW-173 and PBW ZN1. Therefore, present investigation suggest DH-3086 X PBW-343 could be cross with DBW-173, same being DBW-222X PBW ZN1 could be cross with PBW ZN1 for further improvement to develop ideal wheat genotype (high yielding and high stability). The findings could be used to develop commercial wheat varieties that could meet the demands of the farmers and consumers for sustainable agriculture.

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Table 5: Stability analysis on Chlorophyll content, Protein content, Grain filling period and Number of spikelet per spike from three locations using 67 wheat genotypes during 2022-2023 and 2023-2024 *Rabi* seasons (Nov.-April)

S/N	Genotypes	Chlorophyll content			Protein content (%)			Grain filling period			No. of spikelet per spike		
		*		*	*		*	*		*	*		*
	Genotypes	Mean	bi	S^2di	Mean	Bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
1	HD-2967	48.07	-0.16	0.36	11.67	-4.06	0.07	43.16	0.38	6.51	23.65	0.86	0.14
2	DBW-187	48.69	0.91	10.53	11.81	-3.61	-0.07	43.50	0.12	1.19	23.17	3.35	0.46
3	NORMAN	43.11	0.18	2.35	12.02	0.38	-0.07	36.29	0.83	52.21	23.23	3.00	-0.09
4	BORLAUG-100	46.61	0.21	1.58	11.62	-4.29	0.10	42.16	0.37	1.52	23.50	3.23	0.04
5	BHU-25	42.32	0.54	22.25	11.93	-8.66	-0.03	34.41	2.09	-1.08	22.57	3.70	-0.12
6	HD-3117	39.70	-0.24	-2.54	13.44	6.37	2.16	38.25	2.30	17.45	22.22	4.83	-0.25
7	BHU-25 X PBW ZN1	51.10	0.53	-1.74	12.39	8.32	0.04	38.08	-1.02	-2.37	25.17	1.37	-0.23
8	BHU-25 X PBW-343	54.90	0.65	3.48	11.87	-2.61	-0.04	39.50	-0.46	18.70	24.41	0.24	-0.28
9	BHU-25 X HD-3326	54.37	2.46	15.93	12.38	9.06	0.45	40.87	1.65	13.11	24.28	-0.69	0.00
10	DBW-173	41.45	0.59	26.03	12.35	2.501	-0.05	34.00	0.23	0.97	23.93	1.61	0.12
11	DBW-173X PBW ZN1	51.70	2.23	1.82	11.94	-2.65	-0.05	35.66	2.13	-1.95	25.26	0.42	-0.30
12	DBW-173X PBW-343	53.13	2.91	22.53	12.08	2.40	-0.07	35.16	2.03	-2.09	24.60	-2.84	-0.24
13	DBW-173X HD-3326	53.86	1.26	-1.96	12.53	12.25	0.60	43.33	1.70	13.17	24.75	0.95	-0.17
14	DH-3086	41.18	2.05	36.77	12.39	-1.36	0.02	36.79	0.61	38.38	23.86	1.77	0.10
15	DH-3086X PBW ZN1	54.57	1.08	29.52	12.46	13.82	0.99	38.25	1.32	-1.95	24.75	-1.77	-0.06
16	DH-3086X PBW-343	57.14	0.87	-0.29	11.93	-1.83	-0.03	38.25	1.25	21.29	25.16	-0.56	-0.30
17	DH-3086X HD-3326	54.20	1.12	9.73	12.03	4.08	-0.02	38.79	0.76	1.13	25.39	0.00	-0.09
18	DBW-222	51.29	0.82	2.39	12.61	-3.09	-0.01	40.29	1.84	16.61	23.49	2.42	-0.19
19	DBW-222X PBW ZN1	58.04	0.12	-1.07	11.78	2.19	0.02	34.87	0.67	0.19	25.53	1.16	-0.21
20	DBW-222X PBW-343	53.93	-0.18	1.25	12.09	8.23	0.51	40.08	-0.28	85.04	25.93	0.94	-0.19
21	DBW-222X HD-3326	54.44	-0.09	3.51	12.01	1.02	0.28	37.62	-1.05	1.85	24.96	-0.25	0.02
22	CSW-18	46.32	0.31	-3.27	13.72	12.52	0.43	44.25	1.49	1.50	22.72	4.45	0.50
23	CSW-18XPBW ZN1	54.51	1.76	1.24	11.78	-3.02	-0.05	38.79	0.87	4.73	24.59	-1.69	-0.10
24	CSW-18XPBW-343	57.15	0.89	5.26	11.98	2.88	0.01	37.87	-0.85	27.80	24.92	0.24	-0.27
25	CSW-18XHD-3326	56.13	0.64	0.66	11.90	1.90	-0.05	39.41	1.54	-1.46	25.57	0.91	-0.02
26	PBW-757	48.59	0.22	-3.19	13.65	14.97	0.60	35.50	0.81	40.58	22.01	3.28	0.09
27	PBW-757X PBW ZN1	56.40	0.82	26.39	11.99	-3.61	-0.00	38.20	-0.79	19.29	25.82	1.72	-0.19
28	PBW-757X PBW-343	53.67	2.01	-2.15	11.71	0.75	0.01	37.70	1.03	-1.60	25.34	0.16	-0.20
29	PBW-757X HD-3326	51.67	1.49	2.49	12.11	2.60	0.06	38.62	0.10	2.71	25.43	0.71	-0.25
30	BHU-31 X PBW ZN1	51.21	0.37	12.72	12.18	2.51	-0.07	45.79	0.94	0.24	24.84	1.38	-0.27
31	BHU-31 X PBW-343	49.30	1.00	0.46	11.92	-0.30	0.05	41.79	-0.32	48.48	24.82	1.49	-0.29
32	BHU-31 X HD-3326	50.24	1.37	-1.55	11.84	-2.37	-0.05	44.41	1.33	-1.69	24.54	0.53	-0.15
33	WB-02	44.21	0.48	6.13	12.21	-5.77	0.33	36.50	1.47	0.55	22.23	3.64	-0.00
34	WB-02 X PBW ZN1	52.98	1.49	-3.21	12.05	1.52	-0.06	40.91	1.83	7.71	24.65	-0.62	0.08
35	WB-02 X PBW-343	54.90	1.39	-1.24	12.55	14.41	0.88	40.08	1.64	20.16	24.83	-0.12	-0.26
36	WB-02 X HD-3326	49.86	0.92	2.57	11.86	-2.21	-0.03	45.83	1.00	-1.03	24.40	-0.46	-0.20
37	BHU-31	48.23	0.44	8.19	13.48	15.44	2.07	37.91	2.23	17.11	22.89	2.87	-0.15
38	BHU-31 X PBW ZN1	50.80	2.42	-0.85	11.81	-2.08	-0.04	42.08	2.09	0.28	24.97	-1.02	-0.11
39	BHU-31 X PBW-343	51.84	2.70	4.03	12.52	13.91	0.95	40.16	1.83	-1.76	24.36	-0.26	0.25
40	BHU-31 X HD-3326	55.44	1.50	-0.86	12.01	1.91	-0.06	38.25	1.43	51.85	23.96	-0.77	-0.17
41	HD-3721	40.86	0.71	33.77	11.88	-4.75	-0.06	37.83	2.33	14.73	22.42	4.73	-0.20
42	HD-3721 X PBW ZN1	53.11	1.78	23.66	13.01	2.16	3.03	45.66	0.95	2.32	25.27	1.95	-0.20
43	HD-3721 X PBW-343	53.53	1.57	-3.31	12.15	8.40	0.19	42.08	-0.07	83.88	24.26	-1.41	-0.27
44	HD-3721 X HD-3326	53.93	1.37	26.92	11.83	-2.99	-0.05	41.08	1.87	4.00	24.73	0.65	-0.23
45	PWB-725	45.62	0.44	12.91	11.50	-1.73	0.20	35.00	1.90	-1.63	23.00	2.18	0.12
46	PWB-725 X PBW ZN1	52.40	1.30	22.63	12.00	0.91	-0.03	43.33	0.30	3.61	24.07	-1.21	-0.28
47	PWB-725 X PBW-343	53.92	-0.28	-1.12	13.23	18.40	0.10	43.08	0.21	-0.88	25.02	0.83	-0.28
48	PWB-725 X HD-3326	53.18	2.71	13.30	11.82	-2.76	-0.05	42.91	1.63	1.82	24.23	0.58	0.11
49	CRD GEHNU1	49.83	1.79	-2.39	12.57	-5.21	2.03	41.16	-0.51	41.57	23.57	0.95	0.07
50	CRDGEHNU1 X PBWZN1	57.19	-0.10	18.58	11.93	-1.91	-0.03	38.70	-0.47	18.91	24.60	-0.82	-0.20
51	CRDGEHNU1 X PBW343	57.70	0.16	58.26	12.12	0.48	-0.03	34.33	1.58	11.86	24.67	0.85	-0.20
52	CRDGEHNU1 X HD-3326	54.90	1.13	14.73	12.54	5.56	0.20	41.08	0.98	42.86	24.49	-1.08	-0.26
53	PBW-550	44.50	0.67	34.49	11.82	-2.58	-0.04	37.58	2.38	14.92	23.63	1.50	-0.12
54	PBW-550X PBW ZN1	55.72	1.28	-0.579	11.98	-1.36	-0.03	38.91	1.60	23.23	24.99	-0.21	-0.29
55	PBW-550X PBW-343	54.38	0.72	4.88	12.08	1.85	-0.07	38.41	-0.94	-0.67	24.46	-0.61	-0.21
56	PBW-550X HD-3326	57.35	0.56	-3.29	11.88	-1.13	0.01	40.66	0.79	1.05	25.08	1.54	-0.02
57	PBW-677	47.46	0.39	0.61	12.19	1.62	-0.06	38.33	1.22	67.68	23.14	2.92	0.34
58	PBW-677XPBW ZN1	51.41	2.91	14.07	11.89	-3.91	-0.06	34.54	1.63	0.37	24.34	-1.69	-0.28
59	PBW-677XPBW-343	54.91	0.21	-0.04	11.84	-4.89	0.01	30.91	1.27	8.47	25.91	0.54	0.35
60	PBW-677XPBW-343	54.02	1.78	29.94	12.70	12.36	1.03	38.79	1.29	42.93	24.77	-1.60	0.22
61	PBW-822	40.24	-0.03	-1.66	12.32	1.39	-0.04	41.75	1.58	11.36	22.75	0.55	4.73
62	PBW-822X PBW ZN1	57.73	1.51	22.67	12.18	1.84	-0.06	40.83	1.69	20.83	25.08	1.17	0.27
63	PBW-822X PBW-343	57.47	0.60	23.47	12.16	-1.75	-0.04	35.83	0.20	4.00	24.74	0.23	-0.18
64	PBW-822X HD-3326	54.61	1.14	19.68	12.27	2.78	-0.07	39.33	1.13	-0.66	25.58	1.55	1.79
65	PBW ZN1	46.83	0.54	23.56	13.01	14.40	0.64	36.25	2.72	19.61	22.70	2.54	-0.12
66	PBW-343	52.00	0.06	14.23	12.28	6.50	0.92	43.66	0.16	2.50	22.91	3.45	0.35
67	HD-3326	44.49	1.72	76.49	12.98	2.69	3.87	38.91	2.23	20.16	22.66	6.63	-0.12
	Grand Mean:	45.98			11.81			40.52			24.19		
	SE±	0.79			0.06			0.95			0.08		
	C.D.1%:	2.06			0.18			2.46			0.21		

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