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Research Article

Comparison of parametric and non-parametric stability models for yield performance of wheat (*Triticum aestivum* L.) across different agro-climatic zones of Bihar

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Abstract

Genotype × environment (G×E) interaction significantly influences wheat productivity, underscoring the need to identify genotypes with both high yield and yield stability. In this study, 15 bread wheat genotypes were evaluated across eight environments representing three agro-climatic zones of Bihar. Stability analysis employed the Lin and Binns (1988) cultivar superiority index (a parametric measure) and two non-parametric models (Huehn's rank-based stability statistics and Kang's yield-stability index, YSi). Using the Lin and Binns index, genotypes RAUW 120 and DBW 327 had the lowest superiority index (Pi), identifying them as the most stable and widely-adapted. The non-parametric methods gave consistent results: Huehn's statistics and Kang's YSi similarly ranked RAUW 120 and DBW 327 as highly stable. Notably, DBW 303, the highest-yielding genotype, was also ranked among the most stable by Kang's YSi and Huehn's statistics, highlighting its excellent performance. Overall, RAUW 120, DBW 327, and DBW 303 emerged as the most desirable genotypes, with RAUW 120 and DBW 327 showing reliable stability across all methods. These results underscore that using multiple stability indices provides complementary insights for robust genotype selection.

Keywords: Wheat (*Triticum aestivum* L.); G×E interaction; Stability analysis; Lin and Binns index; Huehn's statistics; Kang's yield-stability index

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops worldwide, belonging to the family *Poaceae*. It is a hexaploid species (AABBDD genome composition) and is cultivated on more than 200 million hectares globally, contributing nearly 20% of daily calories and protein requirements of the human population (Curtis, 2002; FAO, 2023). In India, wheat is the second most important cereal after rice, occupying ~31 million hectares with production exceeding 100 million tonnes annually (Braun *et al.*, 2010). Bihar, situated in the North Eastern Plain Zone, contributes significantly to national

wheat output. The state encompasses three agro-climatic zones, further subdivided into sub-zones, characterized by diverse climate, soil fertility, and rainfall patterns. This environmental heterogeneity results in substantial genotype × environment (G×E) interactions, which complicate the process of identifying genotypes that are both high-yielding and widely adapted.

Genotype × environment interactions lead to differential performance of genotypes across locations, and therefore no single genotype can be expected to perform uniformly

in all environments (Crossa, 1990; Dinkar *et al.*, 2025). Consequently, stability analysis has become a central tool in plant breeding to evaluate genotypic performance across multiple locations and seasons (Becker and Léon, 1988; Yan and Kang, 2003). Several parametric and non-parametric models have been proposed for this purpose, each capturing different aspects of stability. Among parametric methods, the Lin and Binns (1988) cultivar superiority index (Pi) is one of the most widely used because of its conceptual simplicity and practical relevance. This index estimates the mean squared deviation of a genotype's yield from the maximum yield in each environment. A lower Pi indicates greater superiority, implying that the genotype consistently produces yields close to the best observed across sites. Thus, Pi provides an integrated measure of both yield potential and stability. In contrast, non-parametric approaches have the advantage of being rank-based and independent of statistical assumptions such as normality. Huehn (1979, 1990) developed several statistics (Si(1), Si(2), Si(3), and Si(6)) that assess the stability of genotype ranks across environments, with lower Si values signifying greater stability. Kang's yield–stability index (YSi) (Kang, 1993) further combines yield rank and stability rank into a single selection criterion, thereby favoring genotypes that excel in both productivity and consistency. Because YSi directly incorporates yield performance, it often highlights high-yielding genotypes with acceptable stability, which makes it particularly attractive for breeders.

Both classes of models have their own strengths. Parametric models like Lin and Binns provide quantitative measures of superiority relative to the maximum yield, while non-parametric methods like

Huehn's and Kang's emphasize rank consistency and practical selection criteria (Mohammadi and Amri, 2008; Sabaghnia *et al.*, 2012). Previous studies have highlighted that using a single method may provide incomplete conclusions, whereas integrating multiple stability models enhances the reliability of genotype recommendations (Becker and Léon, 1988; Yan and Kang, 2003).

The present study was therefore undertaken to evaluate the stability and adaptability of 15 bread wheat genotypes across eight diverse environments of Bihar using one parametric model (Lin and Binns, 1988) and two non-parametric models (Huehn, 1979; Kang, 1993), with the aim of identifying genotypes that combine high yield with stable performance and to examine the extent of agreement among these stability approaches in discriminating genotypic behavior across environments.

MATERIALS AND METHODS

Experimental sites and design: Field trials were conducted during *Rabi* 2023-24 across eight locations in Bihar, representing three agro-climatic zones (Zone I, Zone II, Zone IIIA, and Zone IIIB) as classified by Sattar *et al.* (2021) (**Table 1**). The experimental material comprised 15 wheat genotypes used for stability analysis, whose details are presented in **Table 2**. A randomized complete block design (RCBD) with three replications was adopted. Each plot measured 2.4 m × 6 m with 20 cm row spacing. In the present study, only grain yield was considered for stability analysis. Grain yield was recorded on a whole-plot basis and converted into $q\ ha^{-1}$, and these values were used for all statistical analyses. Standard agronomic practices were followed to raise the crop uniformly across all environments.

Table 1. Particular of the eight environments of different agro-climatic zones of Bihar

	ZONE I	ZONE II	ZONE III A	ZONE III B
Parameter/Locations	Pusa Piprakothi	Purnea Madhepura	Sabour Tilondha	Islampur Mokama
Soil	Sandy loam, loam	Sandy loam, clay loam	Sandy loam, clay loam	Loam, clay
pH	6.5-8.4	6.5-7.8	6.8-8.0	6.8-8.0
Organic Carbon (%)	0.2-1.0	0.2-1.0	0.5-1.0	0.5-1.0
Nitrogen(kg/ha)	150-350	150-300	200-400	200-400
Phosphorus(kg/ha)	5-50	10-35	10-100	10-100
Potassium(kg/ha)	100-300	150-250	150-350	150-350

Table 2. Wheat genotypes evaluated in the study

S.No.	Genotype Name	S.No.	Genotype Name	S.No.	Genotype Name
G1	Sabour Samriddhi	G6	BRW 3922	G11	BRW 3806
G2	BRW 3964	G7	BRW 3921	G12	HD 2967
G3	BRW 3967	G8	RAUW 106	G13	RAUW 121
G4	RAUW 119	G9	DBW 327	G14	DBW 303
G5	RAUW 120	G10	DBW 332	G15	DBW 187

Statistical models applied: The stability of wheat genotypes across environments was evaluated using one parametric model (Lin and Binns superiority index, 1988) and two non-parametric models (Huehn's stability statistics and Kang's yield–stability index). Analysis was performed in R version 4.3.5 (R Core Team, 2024). Packages used: tidyverse (Wickham *et al.*, 2019), metan (Olivoto and Lúcio, 2020), openxlsx (Walker, 2023).

Parametric models.

1. Lin and Binns superiority index (1988)

$$P_i = (1 / 2n) \sum (Y_{ij} - M_j)^2$$

Where P_i = superiority index; Y_{ij} = yield of i^{th} genotype in j^{th} environment; M_j = maximum yield in j^{th} environment; n = number of environments.

Genotypes with low P_i are superior.

Non-parametric models

1. Huehn's stability statistics (1979, 1990)

$$S_i(1) = (1/n) \sum |r_{ij} - \bar{r}_i|$$

$$S_i(2) = (1/(n-1)) \sum (r_{ij} - \bar{r}_i)^2$$

$$S_i(3) = \sum (r_{ij} - \bar{r}_i)^2$$

$$S_i(6) = \sum (r_{ij} - \bar{r}_i)^2$$

Where r_{ij} = rank of i^{th} genotype in j^{th} environment.

Lower S_i values = higher stability.

2. Kang's yield–stability index (1988)

$$Y_{Si} = RY_i + RSi$$

Where RY_i = rank for mean yield; RSi = rank for stability.

Lower Y_{Si} = high yield + stability.

RESULTS AND DISCUSSION

The pooled analysis of variance (ANOVA) across the eight environments showed highly significant effects of genotypes (G), environments (E), and genotype × environment (G×E) interactions. This reflects substantial environmental variability and underscores the necessity

of stability analysis to identify genotypes with consistent performance across Bihar's diverse agro-climatic zones. For instance, strong G×E indicates that genotype performance can vary widely by location, reinforcing the need to evaluate both yield and stability.

Mean Yield Performance and Stability Analysis: Mean yields of the 15 wheat genotypes varied widely from 38.8 to 49.8 q ha⁻¹. DBW 303 recorded the highest mean yield (49.8 q ha⁻¹), followed by DBW 327 (46.6 q ha⁻¹) and RAUW 120 (46.2 q ha⁻¹). The remaining genotypes recorded mean yields within this range, reflecting natural variability among genotypes across environments.

Lin and Binns Superiority Index (P_i): Using Lin and Binns' superiority index (P_i ; **Table 3**), RAUW 120 and DBW 327 exhibited the lowest P_i values, indicating they consistently achieved near-maximum yields across environments and are therefore the most stable genotypes. **Fig. 1.** highlights the superiority of RAUW 120 and DBW 327. These results align with previous studies in wheat and other cereals. For example, Bendjama *et al.* (2019) in durum wheat and Wardofa and Ararsa (2020) in bread wheat similarly confirmed the effectiveness of the Lin and Binns index for identifying well-adapted genotypes. Verma *et al.* (2018) also highlighted the usefulness of parametric stability measures in barley.

Huehn's Stability Statistics: RAUW 120 and DBW 327 had the lowest mean S_i values (smallest rank variability), indicating highly stable performance across environments (**Table 4**). Notably, the high-yielding genotype DBW 303 also exhibited very low S_i values, implying strong rank stability under Huehn's measure. **Fig. 2.** illustrates these differences. The robustness of Huehn's statistics is well documented; Akçura and Kaya (2008) and Kilic (2012)

Table 3. Superiority index (P_i) of wheat genotypes across environments (Lin and Binns, 1988)

S.No.	Genotypes	P_i	Mean yield (qha ⁻¹)
1.	Sabour Samriddhi	89.78	40.36
2.	BRW 3964	67.99	41.13
3.	BRW 3967	71.11	43.05
4.	RAUW 119	59.18	43.52
5.	RAUW 120	14.51	46.15
6.	BRW 3922	54.08	44.62
7.	BRW 3921	119.31	38.82
8.	RAUW 106	47.76	45.81
9.	DBW 327	17.89	46.55
10.	DBW 332	48.33	43.16
11.	BRW 3806	62.90	43.81
12.	HD 2967	80.63	41.45
13.	RAUW 121	52.37	43.85
14.	DBW 303	3.38	49.77
15.	DBW 187	31.58	45.99

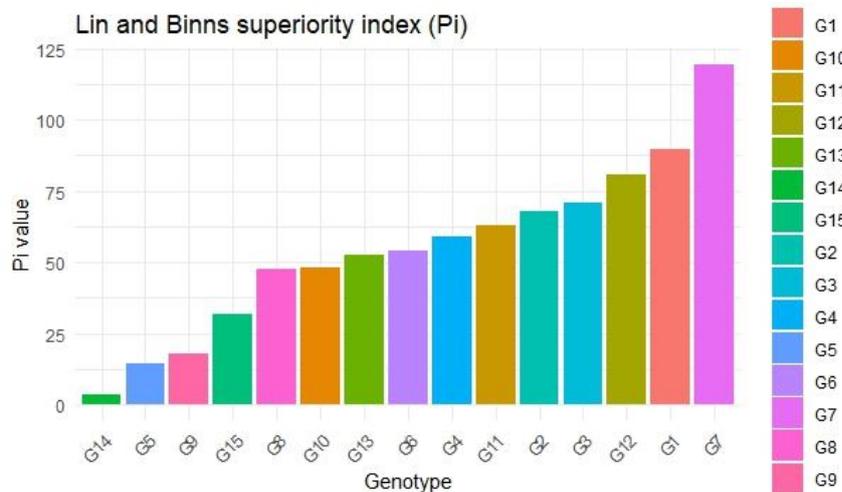


Fig. 1. Superiority index (Pi) values of wheat genotypes across environments (Lin and Binns model)

Table 4. Non-parametric stability statistics (Si(1)–Si(6)) of wheat genotypes following Huehn (1979).

S.No.	Genotypes	Si1	Si2	Si3	Si6	Mean yield (qha ⁻¹)
1.	Sabour Samriddhi	2.93	15.92	13.93	111.5	40.36
2.	BRW 3964	0.90	1.55	1.35	10.87	41.13
3.	BRW 3967	2.87	11.55	10.10	80.87	43.05
4.	RAUW 119	3.18	16.21	14.18	113.5	43.52
5.	RAUW 120	0.71	0.83	0.73	5.87	46.15
6.	BRW 3922	2.81	12.78	11.18	89.5	44.62
7.	BRW 3921	2.34	7.55	6.60	52.87	38.82
8.	RAUW 106	5.5	37.42	32.75	262	45.81
9.	DBW 327	1.25	2	1.75	14	46.55
10.	DBW 332	2.12	6.69	5.85	46.87	43.16
11.	BRW 3806	2.21	7.125	6.23	49.87	43.81
12.	HD 2967	1.81	8.21	7.18	57.5	41.45
13.	RAUW 121	2.46	11.41	9.98	79.87	43.85
14.	DBW 303	0.62	0.55	0.48	3.87	49.77
15.	DBW 187	2.31	7.35	6.43	51.5	45.99

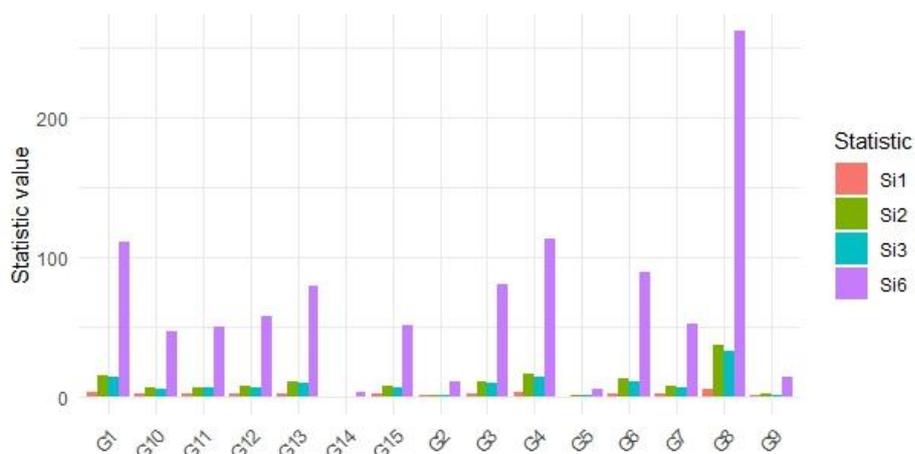


Fig. 2. Stability statistics (Si values) of wheat genotypes across environments (Huehn model)

emphasize that these non-parametric measures are less sensitive to distributional assumptions and effectively highlight consistently ranked genotypes, much like our stable RAUW 120, DBW 327 and DBW 303. Similar conclusions were drawn by Kumar *et al.* (2023), who found Huehn's statistics highly effective for stability analysis in rice under comparable conditions.

Kang's Yield–Stability Index (YSi): Kang's yield–stability index (YSi; **Table 5**) placed DBW 303 as the top-ranked genotype (lowest YSi), followed closely by RAUW 120 and DBW 327. This reflects their superior combination of high yield and stability (**Fig. 3**). Such a result—where a high-yielding genotype is favored by YSi—has been noted previously. Akçura *et al.* (2009) and Yaghotipoor *et al.* (2017) observed that Kang's YSi effectively identifies high-yielders with acceptable stability. Likewise, Akbari *et al.* (2022) reported a similar pattern

in lentil, indicating that YSi offers a practical and reliable approach for cultivar recommendation under challenging environments.

Comparative Insights and Genotype Recommendation: Taken together, RAUW 120, DBW 327, and DBW 303 were consistently identified as superior genotypes by the stability models. RAUW 120 and DBW 327 were ranked as highly stable by all three methods, whereas the high-yielding DBW 303 performed best under Kang's YSi and Huehn's statistics. The convergence of results from parametric and non-parametric methods strengthens the credibility of these selections (**Fig. 4**). This multi-model synergy has been advocated by Thennarasu (1995), who developed foundational non-parametric procedures, and by Yaghotipoor *et al.* (2017), who argued that a multifaceted approach provides a more holistic and reliable assessment of genotype stability.

Table 5. Yield stability index (YSi) of wheat genotypes as per Kang (1988)

S.No.	Genotypes	Mean yield (qha ⁻¹)	Rank yield	Si1	Rank stability	YSi
1.	Sabour Samridhi	40.36	14	2.93	13	27
2.	BRW 3964	41.13	12	0.90	3	15
3.	BRW 3967	43.05	11	2.87	12	23
4.	RAUW 119	43.52	10	3.18	14	24
5.	RAUW 120	46.15	3	0.71	2	5
6.	BRW 3922	44.62	6	2.81	11	17
7.	BRW 3921	38.82	15	2.34	9	24
8.	RAUW 106	45.81	5	5.5	15	20
9.	DBW 327	46.55	2	1.25	4	6
10.	DBW 332	43.16	8	2.12	6	14
11.	BRW 3806	43.81	9	2.21	7	16
12.	HD 2967	41.45	13	1.81	5	18
13.	RAUW 121	43.85	7	2.46	10	17
14.	DBW 303	49.77	1	0.62	1	2
15.	DBW 187	45.99	4	2.31	8	12

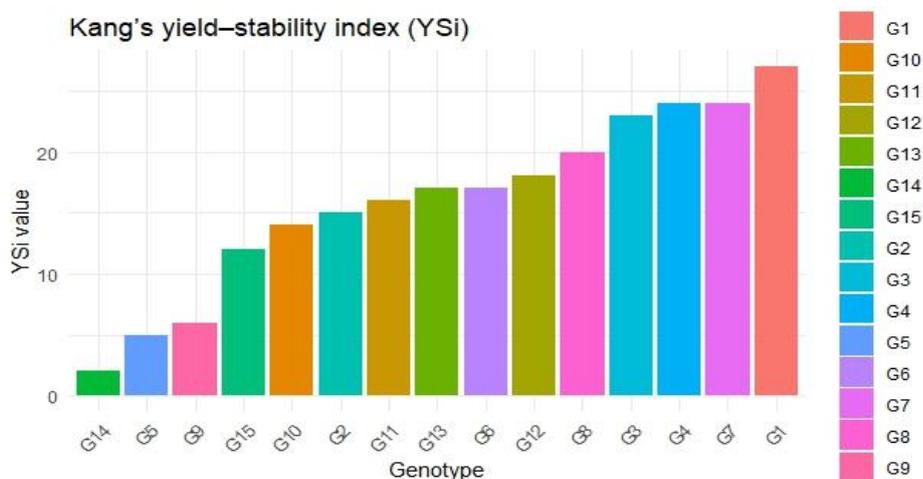


Fig. 3. Yield stability index (YSi) of wheat genotypes across environments (Kang model)

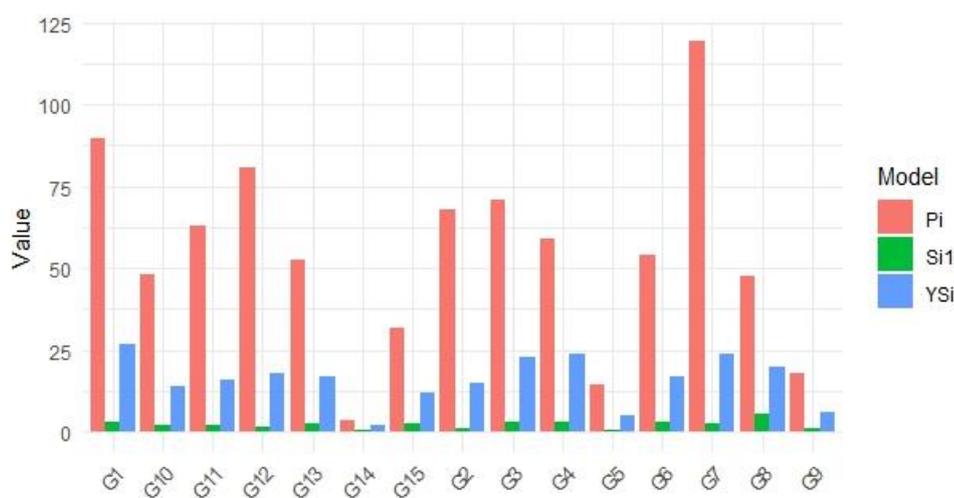


Fig. 4. Comparative summary of stability results from parametric and non-parametric models for wheat genotypes

While RAUW 120 and DBW 327 offer yield stability across Bihar's varied agro-climatic conditions, DBW 303 offers higher yield responsiveness under optimal management. These findings illustrate the importance of employing multiple stability approaches for robust varietal selection, as also suggested by Crossa (1990) and Yan and Kang (2003). Verma *et al.* (2018) and Viswanathan and Nadarajan (2023) similarly emphasized that using a combination of stability indices enhances the reliability of genotype selection under variable environments.

The present study demonstrated significant genotype × environment interaction, indicating differential performance of wheat genotypes across environments. Stability analysis using parametric and non-parametric models consistently identified RAUW 120, DBW 327 and DBW 303 as superior performers. RAUW 120 and DBW 327 exhibited high stability across environments, while DBW 303 recorded the highest mean grain yield along with good stability performance. The consistency among Lin and Binns superiority index, Huehn's statistics, and Kang's yield–stability index strengthens the reliability of these findings. Therefore, RAUW 120, DBW 327, and DBW 303 may be considered promising genotypes for wider adaptation across the agro-climatic zones of Bihar, subject to further multi-year evaluation.

Author contribution

Ashutosh Kumar (AK), Sudhir Kumar (SK), and Radhey Shyam Singh (RSS) designed the research plan and conducted the field experimentation. Ashutosh Kumar (AK) and Priyanka Kumari (PK) were involved in data collection. Abhishek Tiwari (AT), Kumar Saket (KS), Muskan Parveen (MP), and Shubham Chandra (SC) contributed to data analysis and statistical interpretation. Brajesh Kumar (BK) assisted in manuscript preparation, editing, and refinement. All authors read and approved the final manuscript.

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